Appendix E

Hydrology and Hydraulics Analysis

Appendix E
Hydrology and Hydraulic Engineering Considerations

1. Regional Hydrology

1.1 Climate

The project site and the surrounding area are characterized by a Mediterranean climate with warm, dry summers and cool, wet winters (California Coastal Conservancy and U.S. Army Corps of Engineers 1998). The climate is strongly influenced by conditions in San Francisco Bay and, to a lesser extent, the Pacific Ocean. July is typically the warmest month, with a mean daytime temperature of approximately 80° F. January is the coldest month, with a mean daytime temperature of approximately 54° F. Differences in minimum and maximum daily temperatures are approximately 30° F in the summer months and 15–20° F in the winter (U.S. Army Corps of Engineers 1987).

Precipitation near the project site ranges from approximately 22 to 30 inches per year, with 90% falling between the months of November and April (U.S. Army Corps of Engineers 1987), primarily in the form of rain. Even in the upper watersheds, snowfall is rare, and snowmelt does not contribute significantly to runoff (Jones & Stokes 2001).

Wind direction frequency plots show a uniform directional distribution. The highest mean wind speeds originate from the northwest (10.4 mph) and southeast (8.8 mph) (California Coastal Conservancy and U.S. Army Corps of Engineers 1998).

1.2 Tides

Tides in San Pablo Bay follow a mixed semidiurnal cycle, with 2 high tides of unequal elevation and 2 low tides of unequal elevation per day. Average high tide elevation values are referred to as *mean higher high water* (MHHW) and *mean high water* (MHW). Similarly, low tide peaks are referred to as *mean low water* (MLW) and *mean lower low water* (MLLW). Events such as storm high tides that exceed the elevation of MHHW are referred to as *extreme high tide* (EHT).

Because of geographic and hydrodynamic complexities, tidal characteristics, including the elevations of average high, low, and mean tides, differ substantially throughout the San Francisco Bay–San Pablo Bay system. Tide cycles in San Pablo Bay typically lag behind those at the Golden Gate by as much as 75 minutes (U.S. Army Corps of Engineers 1996). However, within San Pablo Bay itself, comparison of tide levels within Novato Creek and those observed at the mouth of the Petaluma River indicates that the lag time is negligible between these sites (Philip Williams & Associates 1998).

Table 2-2 shows statistical tidal information for the project site, obtained from measurements made by NOAA/NOS at the mouth of the Petaluma River (Tide Gage #941 5252) (NOAA/NOS 1981). Table 2-2 also shows the expected elevation of a 100-

year tide in San Pablo Bay. The 100-year tide represents a tide that has a 1 in 100 chance of occurring in any given year.

Note that NOAA is currently working on refinements to tidal datum information for this specific project site.

Table E-1. Tide Information from the Petaluma River Entrance

Tide Level	Feet above MLLW Datum	Feet above NGVD 29 Datum
100-year Event (SF COE)[1]	9.63	7.00
Mean Higher High Water (MHHW)[2]	6.06	3.43
Mean High Water (MHW)[2]	5.49	2.86
Mean Tide Level (MTL)[2]	3.24	0.61
NGVD 1929[2]	2.63	0.00
Mean Low Water (MLW)[2]	1.00	-1.63
Mean Lower Low Water (MLLW)[2]	0.00	-2.63

Sources: U.S. Army Corps of Engineers, 1994 (1), NOAA/NOS, 1981 (2)

Tide data recently collected by San Francisco International Airport's Airfield Development Engineering Consultant (2000) at the mouth of the Petaluma River correspond closely to the NOAA/NOS data shown in Table E-1. The ADEC data consist of water surface measurements taken at 10-minute intervals over a 30-day period from June 15, 2001 to July 15, 2001. The MHW computed from the ADEC dataset is 0.14 feet below the value reported by NOAA; the MLW computed from the ADEC dataset is 0.07 feet above the value reported by NOAA.

1.3 Surface Water Drainage Patterns

The project site is located in a watershed bounded by the hills of central and northern Marin County (a portion of the California Coast Ranges) to the west and by San Pablo Bay to the east (see Figure 2-1). The upland areas have elevations of 1300–1600 feet NGVD 29 and support mixed open grasslands, oak woodlands, and chaparral (California Coastal Conservancy and U.S. Army Corps of Engineers 1998). The lowlands have elevations as low as several meters below mean tide level (MTL) and consist of agricultural fields that were reclaimed from the Bay by levee in the late 1800s.

In the San Francisco Bay region, the permeability of both soils and underlying bedrock is typically low. As a result, infiltration rates are slow, runoff rates are correspondingly high and strongly dependent on precipitation, and base flow is poorly sustained. Most streams are ephemeral (Jones & Stokes 2001).

Major site features on and near the project site are described in the following sections.

1.4 Pacheco Creek

Pacheco Creek drains a watershed of approximately 1.9 square miles. It originates 3 miles west of Hamilton Army Airfield on Big Rock Ridge, crosses several roadways, including U.S. Highway 101, via culverts, and discharges into Pacheco Pond (California Coastal Conservancy and U.S. Army Corps of Engineers 1998). Hydrologic studies completed for the Hamilton Airfield wetland restoration plan estimated the 10-year and 100-year discharges entering Pacheco Pond at 582 and 1,041 cubic feet per second (cfs) respectively (Philip Williams & Associates 1998).

The *lower reach of Pacheco Creek* is defined as the region downstream of the Northwest Pacific Railroad Bridge crossing. In this reach, overtopping due to downstream backwater effects is known to occur for flows smaller than the 10-year event (California Coastal Conservancy and U.S. Army Corps of Engineers 1998, Philip Williams & Associates 1998). When flooding occurs, overflow is directed toward Landfill 26 and back to Pacheco Pond over the Ammo Hill saddle if the water surface elevation exceeds 7.7 feet NGVD 29 (Philip Williams & Associates 1998).

1.5 Arroyo San Jose

Arroyo San Jose drains a watershed of approximately 5.4 square miles. Like Pacheco Creek, Arroyo San Jose has its headwaters on Big Rock Ridge and discharges into Pacheco Pond. The 10-year and 100-year discharges are 1,369 and 2,455 cfs, respectively (Philip Williams & Associates 1998). Arroyo San Jose accounts for approximately 75% of the inflow to Pacheco Pond (Philip Williams & Associates 1998).

Arroyo San Jose is expected to remain within its banks during floods as large as the 100-year event, with the exception of the lower reaches, where high stages in Pacheco Pond can cause overtopping due to backwater effects (California Coastal Conservancy and U.S. Army Corps of Engineers 1998).

1.6 Pacheco Pond

Pacheco Pond, also known as Ignacio Reservoir, was constructed by the Marin County Flood Control and Water Conservation District (MCFCWCD) as a detention basin for flows from Pacheco Creek and Arroyo San Jose. It also provides freshwater wetland and wildlife habitat. The pond is jointly managed by the MCFCWCD and the California Department of Fish and Game (CDFG).

Pacheco Pond covers an area of approximately 120 acres and has an estimated flood storage volume of 866 acre-feet at an elevation of approximately 7 feet NGVD 29 (see attached NHC memorandum dated 14 October 2002). It discharges into Novato Creek via a levied channel controlled by a weir structure with an invert elevation of –0.86 feet NDVD 29 (PWA, October 1998) which has six 4-foot by 4-foot flap gates. Two slide-gated siphons formerly served to drain overflow from the pond to HAAF; however, these structures are not in operation at present (Philip Williams & Associates 1998).

A sill at the upstream face of the Bel Marin Keys Blvd. culvert controls water surface elevations in Pacheco Pond. Inserting flashboards on the upstream side of the culvert can raise the minimum pond elevation. An operating agreement between the MCFCWCD and CDFG establishes the desired water surface elevation in the pond at 1.5 feet above MSL. The minimum pond water surface elevation is equivalent to the sill elevation of the culvert (approximately –0.8 feet NGVD 29). The actual low-flow water surface elevation in the pond is assumed to be approximately 0 feet NGVD 29 (see attached NHC memorandum dated 14 October 2002).

During high flow events, the water level in Pacheco Pond may exceed the elevation of adjacent levees. The lowest point in the levees (elevation 5.6 feet NGVD 29) is north of the pond, adjacent to the Leveroni property. However, overtopping occurs primarily on the west side of the pond near Ignacio Business Park and near the confluence of the outflow channel with Novato Creek (Philip Williams & Associates 1998).

1.7 Novato Creek

Novato Creek is the principal drainage in the project vicinity, and has an approximate total watershed area of 44 square miles (U.S. Army Corps of Engineers 1987). The Corps has computed 10-year and 100-year discharges near the Highway 101 crossing at 3,420 cfs and 6,230 cfs, respectively (U.S. Army Corps of Engineers 1987), and recognizes an “ultimate flow” of 8,000 cfs at the mouth of Novato Creek. However, the railroad bridges downstream of Highway 101 and adjacent to Highway 37 constrict flow, causing overtopping upstream of the lowest reach of Novato Creek and reducing the actual discharge in the lower reaches of the creek; the 8,000-cfs value in particular is unlikely to pertain to the reaches of Novato Creek adjacent to the BMKV site (CSW/Stuber-Stroeh Engineering Group 1996).

Additional modeling efforts have shown that the tidal influence extends upstream of Highway 101 to the City of Novato during flows greater than the 10-year event (FEMA 1998).

1.8 Bel Marin Keys Development

The Bel Marin Keys development is located adjacent to the northwest boundary of the BMK-V project site. Bel Marin Keys is a waterfront residential community with 2 internal constructed lagoons that offer access to Novato Creek though a system of locks. The Bel Marin Keys community uses Novato Creek for boat access to San Pablo Bay and relies on tidal changes in water level to periodically exchange flow between the Bel Marin Keys lagoons and San Pablo Bay.

Water level is managed at 2 feet NGVD 29 in the north lagoon and 0.5–1 foot NGVD 29 in the south lagoon (CSW/Stuber-Stroeh Engineering 1996). Storm water drainage from Bel Marin Keys South Lagoon discharges into the project site via a weir in the levee on the eastern edge of the south lagoon. Storm water may also be discharged to Novato Creek via the boat access lock on the east or gated culverts on the west sides of the South Lagoon. Discharge into Novato Creek is limited by stage in the creek; during high-flow periods, runoff is impounded in the lagoons until flow in Novato Creek recedes (CSW/Stuber-Stroeh Engineering 1996).

1.9 Hamilton Army Airfield

The former HAAF property is located south of the BMKV project site. The HAAF site receives flood overflows from Pacheco Creek via a 48-inch flap gate that serve the Landfill 26, Ammo Hill, and POL Hill areas. Under some conditions, HAAF receives overflows from Pacheco Pond via 2 slide-gated siphons, although these siphons are not presently operational (Philip Williams & Associates 1998). Flood overflows also enter the HAAF site from the BKMV parcel, through a levee gap approximately 2,000 feet southeast of the HAAF site's northwest corner under some conditions.

1.10 Existing Flood Protection Benefits Provided by Bel Marin Keys V Site

The BMKV site is under F-1 (primary floodway) and F-2 (secondary floodway) overlay zoning pursuant to the Marin Countywide Plan (County of Marin 1994), and is subject to flood protection covenants that further restrict development to ensure that the site continues to fulfill a flood protection function for adjacent parcels. Under existing conditions, the designated flood protection function of the site is to accommodate overflow from Pacheco Pond, Novato Creek, and the constructed South Lagoon at the Bel Marin Keys development.

Based on modeling of water surface elevations by Northwest Hydraulics (see App. E, section 5) and analysis of existing topography and infrastructure, the following sequence of overflow events is expected to occur in response to a flood of approximately 10-year magnitude. The 100-year flood event is expected to generate a sequence of overflow events similar to that modeled for the 10-year flood.

Backwater effects propagating upstream from the confluence of the Pacheco Pond outflow channel with Novato Creek lead to overtopping and overland inundation in Ignacio Business Park. Overland runoff drains southeast toward Ammo Hill; some may return immediately overland to Pacheco Pond, with the remainder draining southward toward the Landfill 26 area.

In floods approximating the 10-year event, water surface elevation in Novato Creek adjacent to the Bel Marin Keys South Lagoon outlet lock is expected to be approximately 5.8 feet NGVD 29. The low point in the Novato Creek levee has an elevation of approximately 5.6 feet (San Francisco International Airport, 2001). The 10-year event and larger floods are thus likely to generate overflow from Novato Creek onto the BMKV site. However, because of the height of the levee separating Pacheco Pond from the BMKV site, the pond is unlikely to overtop the levee in events up to and including approximately the 100-year flood

Under existing conditions, storm water runoff that enters the BMKV site is ponded. It is reduced by evaporation or by pumping and discharge into San Pablo Bay. Net infiltration into the groundwater is not thought to occur on the site.

2. Sediment Budget and Site Evolution

The sediment budget in the San Francisco Bay–San Pablo Bay system is a key factor in restoration design, because the design development process relies on natural delivery of sediment to transform the framework created by restoration construction into a functioning mature marshland over time. The fine sediment fraction (suspended load and fine bed load) is particularly important because it provides the primary sedimentary building blocks for naturally evolving tidal marsh regimes. The following sections provide additional information on sediment loading in the San Pablo Bay system, with a focus on the fine (suspended load) fraction.

2.1 Suspended Sediment Loading in the San Francisco Bay Estuary

A balance of factors controls suspended sediment concentration. Important influences on suspended sediment loading include wind speed and direction (i.e., the magnitude of wind-driven waves and strength of wave currents), freshwater influx, and tidal currents (Northwest Hydraulic Consultants 2001). Freshwater influx shows a strong seasonal variation, with a peak during the winter (November–April) rainy season; land-derived sediment loading shows a corresponding peak in the winter. Tidal currents vary on a semi-monthly basis from neap tides to spring tides, with the greatest sediment mobility at spring tides.

Throughout the year, suspended sediment concentrations are generally highest in the North Bay region and at the southern end of the Bay. USGS data show average concentrations of ~80–150 milligram/liter (mg/l) in San Pablo Bay and 100–200 mg/l in the South Bay for water years 1997 and 1998. Sediment concentrations are typically lower in the central portion of the Bay (Northwest Hydraulic Consultants 2001).

Relatively small creeks feed many of the North Bay's sloughs. Sediment concentrations in these sloughs ranges 41 to 386 mg/l and typically decreases with increasing distance from San Pablo Bay (Warner and Schoellhammer 1999, Buchanan and Ruhl 2000), because the Bay is their primary source of sediment. By contrast, the larger Petaluma River system carries a substantial suspended sediment load because of its larger watershed. Sedimentation rates at locations on the margin of San Pablo Bay near the river mouth (e.g., Bel Marin Keys, Port Sonoma Marina, and Petaluma Marsh) are as much as 0.5–1.3 feet per year (U.S. Army Corps of Engineers 1998).

2.2 Gold Rush Era Effects on SF Bay Sediment Budget

The hydraulic mining that occurred in the foothills of the Sierra Nevada from 1850 to 1884 resulted in the discharge of large amounts of sediment into streams and rivers draining westward toward the San Francisco Bay estuary. The sediment load contributed by hydraulic mining was substantially in excess of the system's natural load, and large amounts of sediment were deposited in the northernmost embayments in the estuary, resulting in infilling and accretion of a significant portion of Suisun and San Pablo Bays.

A key question for restoration design now centers on expected annual sediment loading and deposition rates around the Bay. While a number of studies suggest that excess sediment related to hydraulic mining is no longer being delivered to the Bay in large amounts, diversion and detention of Central Valley waters since about 1950 has also significantly altered freshwater discharge into the Bay system, and there is disagreement among restoration proponents regarding both the anticipated sediment budget and realistic water discharge values.

2.3 Sediment Budget Assumptions for Restoration Design

In order to provide a basis for restoration design at Bel Marin Keys, Northwest Hydraulics Consultants (2001) modeled yearly sediment loading in San Pablo Bay based on average monthly water discharge values and observed concentrations of suspended sediment for water years 1997 and 1998. Water discharge data were obtained from U.S. Geological Survey (USGS) stream gages located immediately upstream of the Bay estuary (the Freeport gage on the Sacramento River and the Vernalis gage on the San Joaquin River). Data on suspended sediment concentration (SSC) were taken from the USGS near-bottom sensor at the Benecia Bridge in Suisun Bay (USGS 1999, USGS 2000).

3. Navigation

No negative impacts to Federal navigation channels are expected from the combined HWRP and BMK-V project.

There may be potential effects to the small navigable channel in lower reaches of Novato Creek due to potential alternatives of the BMK-V expansion. In particular, Alternatives 1 and 2 currently propose tidal breaches to Novato Creek.
These tidal breached will likely have a small positive effect on the channel width and depth in Novato Creek below the breaches. It is recommended that during future project studies the potential navigation changes to Novato Creek be evaluated and quantified. These studies and findings should be coordinated with the Bel Marin Keys Community Service District and residents, since they are the primary group that utilizes this channel for navigation.

4. Water Control Structures

The primary water control structures associated with the Revised Alternative 2 of the BMK-V expansion of the HWRP are:

- Two Overflow weirs from the BMK South Lagoon into the constructed seasonal wetland swale;
- One Outlet culvert with flap gate to Novato Creek out of the seasonal wetland swale;

- Weir and outlet culvert with flap gate from Pacheco Pond into the seasonal wetland and a weir and outlet culvert with flap gate from the seasonal wetland into the tidal wetland; and
- Temporary water control pumps or weirs associated with the control of dredged material process water and site storm water during construction.

During the Pre-construction, Engineering and Design (PED) phase the design requirements for the necessary water control structures will be finalized. However, none of these structures are expected to be atypical or extraordinary. Therefore, the design and construction of these features is expected to relatively routine.

The overflow weirs from the BMK South Lagoon into the seasonal wetland swale will require hydrological analysis to determine the design flow rate and appropriate structural design for integration into the improved South Lagoon Levee. These requirements will be incorporated into the final construction plans and specifications.

The outlet culvert with flap gate to Novato Creek out of the seasonal wetland and the outlet culvert with flap gate from Pacheco Pond into the tidal wetland will also require hydrological analysis to determine the design flow rates and structural design for integration into the project berms and levees.

Based on the final wetland design template and the dredged material placement plan the temporary water control pumps or weirs associated with the control of dredged material process water and site storm water during construction will require basic design and development of a performance based specification to incorporate into the dredged material placement contract.

5.0 Hydraulic Modeling and Flood Zoning

The following pages contain Memoranda from North West Hydraulics Consultants summarizing their hydraulic modeling efforts for the project, including currently available results and plans for further study. Descriptions of local Flood Zoning Ordinances covering the BMK-V parcel are also provided in the Memoranda.

Memorandum

northwest hydraulic consultants
3950 industrial boulevard, suite 100c
west sacramento, ca 95691
(916) 371-7400
(916) 371-7475 (fax)

Date:	14 October 2002	**Project:**	50283
To:	Rich Walter		
Company/Agency:	Jones & Stokes		
From:	Brad Hall		
Subject:	Hydrologic and Hydraulic Modeling Assessment of Existing and Project Alternatives at Bel Marin Keys V		

This memorandum is issued to clarify citations presented in the 18 April 2002 memorandum. The analyses, results, and conclusions of this memorandum were not modified from the 18 April 2002 memorandum.

Overview

This document presents Northwest Hydraulic Consultants (**nhc**) investigation of the hydraulic impact of the proposed Bel Marin Keys tidal marsh restoration project. This study quantitatively assesses the relative change of the proposed project on Pacheco Pond stages and Novato Creek stages from the Pacheco Pond outlet to the creek mouth.

The proposed tidal marsh restoration at Bel Marin Keys will affect the hydrology of several elements within the lower Novato Creek basin. Proposed modifications to Pacheco Pond and the proposed diversion of flow away from Novato Creek considered in the design alternatives will present the most substantial effects. The proposed modifications to Pacheco Pond consist of either expanding the existing pond, or creating a seasonal marsh adjacent to the pond. In addition, the diversion of water currently flowing into Novato Creek from Pacheco Pond, to the proposed tidal marsh will greatly affect existing conditions on the Bel Marin Keys tidal wetlands restoration site. These flows will provide fresh water for the proposed freshwater marsh portion of the project.

To assess the impacts of the proposed tidal wetland restoration on the hydrology of the existing site a review of hydrologic studies of the Novato Creek and Pacheco Pond watersheds was completed. Existing and proposed site conditions that affect the drainage and flooding characteristics were identified. Representative flood hydrographs and tidal stage characteristics were determined and used for computing flood stage and discharge conditions in the study area. To quantify the changes in flood stage and discharge magnitude resulting from coincident terrestrial and tidal flood conditions, a one-dimensional, unsteady flow model of the Novato Creek and Pacheco Pond system was developed. Described below are some features of this modeling effort, including a description of the basin, the proposed alternatives, the model itself, and the model results.

Basin Description

The components of the Pacheco Pond watershed consist of two small streams, Pacheco Creek and Arroyo San Jose, which drain into a constructed detention reservoir, Pacheco Pond. Pacheco Pond currently discharges into Novato Creek and finally, San Pablo Bay (Figure 1). Historically, Pacheco Creek and Arroyo San Jose discharged into the tidal marsh to the south of the Bel Marin Keys development. The specific features of the watershed are described below.

- *Pacheco Creek*

Pacheco creek drains a 1.9 square mile watershed. From the headwaters 3 miles to the west, the stream crosses several roads, including Highway 101, through a series of culverts. Flooding is known to occur in the lower reaches of Pacheco Creek, prior to entering Pacheco Pond, for flood events with magnitudes less than the 10-year event (1).

However, because this study focused on the area downstream of Pacheco Pond, the flooding of the creek upstream of the pond was not analyzed in the modeling study. Flows of Pacheco Creek into the pond were modeled as an inflow hydrograph entering the pond, as will be described below. Additional survey of channel cross sections and physical characteristics of the local storm drainage system would be required to quantify flooding conditions upstream of Pacheco Pond and within the Ignacio Business Park.

- *Arroyo San Jose*

The Arroyo San Jose watershed drains an area of approximately 5.4 square miles. Arroyo San Jose accounts for approximately three-quarters of the inflow to Pacheco Pond (2). Previous hydrologic studies of the basin indicate that the Arroyo San Jose remains within its banks for flood events up to the 100-year flood. However, accompanied with high tides in Novato Creek and the associated constriction of flow release from Pacheco Pond, the 100-year event can cause minor flooding of residential and business areas near the confluence with Pacheco Pond (1).

- *Pacheco Pond*

Pacheco Pond covers an area of approximately 120 acres. The estimated flood storage volume between elevations 0.0 and 7.0-ft, NGVD 29, is approximately 866 acre-ft. The storage volume of the reservoir was estimated from existing topographic surveys, aerial photos, and previous engineering studies (3, 4). A stage-volume relation for Pacheco Pond was determined and utilized to compute the pond storage and resultant water surface elevation during storm events.

Pacheco Pond discharges into Novato Creek via a leveed channel controlled by six 4-ft by 4-ft flap gated culverts. The invert elevation of the culvert structure was independently surveyed by **nhc** and the Marin County Flood Control District to have an invert elevation of –0.86-ft, NGVD 29. It appears that the invert of the culvert was not accurately surveyed in earlier studies of Pacheco Pond hydrology, and was reported to have an invert elevation of –1.8-ft, NGVD 29 (2). The effect of the flap gate was modeled by only allowing flow in the positive direction (toward Novato Creek) through the box culvert. Minor leakage and backflow through the flap gates was not modeled in this analysis.

During high flow events the water level in Pacheco Pond can exceed adjacent levee elevations. The lowest point exists north of the pond, adjacent to the Leveroni property, where the measured low point of the levee is 5.6-ft, NGVD 29 (2). These low points were considered in the model by including lateral weirs to direct flow to adjacent storage areas when stages in the pond exceeded 5.6-ft. Top of levee surveys also indicate that a significant extent of this levee is at an elevation of approximately 6.7-ft, NGVD 29. Additional lateral overflow weirs were specified at this higher top of levee elevation in the hydraulic model.

- *Novato Creek*

Novato creek is the main drainage course in the region with an approximate total watershed area of 44 square miles (5). However, breakout flows due to flow constrictions at the railroad bridges downstream of Highway 101, and adjacent to Highway 37, reduce the overall peak flood discharge (6).   An infinite variation in the timing of peak discharges between Novato Creek and Pacheco Pond hydrographs is possible; however, the Novato Creek peak would be expected to lag the Pacheco Pond peak due to the larger watershed area of Novato Creek. Water surface conditions within Pacheco Pond and within Novato Creek were evaluated for lag times between peak flows of zero, six, and 12 hours.

Cross sections of Novato Creek were developed by **nhc** from existing LiDAR (3) and bathymetric surveys (7). The cross sections depict the subtidal channel of the creek, adjacent tidal marsh surface, and existing levee structures that currently constrain the Novato Creek floodplain. Top of levee surveys completed in 1996, indicate that the levee crest between Novato Creek and the Bel Marin Keys V site dips to an elevation of approximately 5.6-ft, NGVD 29, at a point approximately 1000 feet downstream from the Bel Marin Keys South Lagoon navigation lock. Overtopping of this levee was observed by Bel Marin Keys residents in the February 1998 flood event. The location of this overtopping was incorporated in the hydraulic model by specifying an overtopping weir with a crest elevation of 5.6-ft, in the model geometry at this location.

- *San Pablo BayTides*

Tides in San Pablo Bay follow a mixed semidiurnal cycle, with two high and two low tides, of differing heights, occurring in a single day. Due to geographic and hydrodynamic complexities, mean tide levels vary throughout the San Francisco/San Pablo Bay system. Tide cycles in San Pablo Bay are seen to lag those at the Golden Gate by as much as 75 minutes (2). Peak tide water surface elevations in the vicinity of Novato Creek are reported as 6.0-ft, NGVD 29 for the 10-year tide and 6.5-ft, NGVD 29 for the 100-year tide (8). FEMA maps tidal water surface elevations to the nearest whole-foot (9). Therefore, the Base Flood Elevation resulting from tidal flooding in the City of Novato is 7 feet (10).

Storm events lead to higher tidal stages than those predicted by gravitational forces for a variety of reasons. First, low barometric pressures associated with significant storm frontal passage leads to a regional rise in tidal stage as the oceans surface level increases in response to the reduction in overlying atmospheric pressure. Second, wind stresses may lead to a storm surge setup, further increasing peak tidal stage. Third, increases in large scale regional runoff from the Sacramento and San Joaquin watersheds, as well as contributions from San Francisco Bay watersheds, limit the low tidal excursion of normal tidal cycles. San Pablo Bay, in essence, is filled with regional runoff (11).

The tide measurements taken at the mouth of the Petaluma River were utilized to develop time series of tidal stage hydrographs at the mouth of Novato Creek. These data, completed as part of the San Francisco Airport runway expansion dredge material disposal studies, consist of tidal stage measurements recorded at 10-minute increments for the duration of approximately one month (14 June - 17 July 2000) (3). Earlier studies of Novato Creek indicate negligible differences between Novato Creek and Petaluma River tidal stage characteristics (2). To conservatively estimate tidal conditions during flood events, these tide stage data were modified in two ways to reflect extreme tidal conditions that occur during significant flooding events. The first modification was to increase the observed peak tidal stage by one foot to reflect extreme high tides due to low atmospheric pressure and wind setup in the region. This is equivalent to coincident tidal stage boundary conditions frequently used by the Corps of Engineers and the FEMA for flood control design or flood hazard mapping studies on tidally influenced streams and rivers (12). The resulting peak tide is 5.75 feet, 0.25 feet lower than the 10-year peak tide of 6 feet. The second modification was to truncate the low tide elevation at the mean tide level to represent limits on low tide excursion due to extreme regional, basin-wide runoff conditions.

Alternative Descriptions

The descriptions of Alternatives 1, 2, and 3, given below consist of that information that is relevant to the hydrologic modeling effort. That is, only the elements that affect the hydrology and hydraulics of the site are considered. For all project alternatives, Pacheco Pond flows will be routed to Novato Creek during storm events. In the following analyses, Pacheco Pond flows were routed to the restored tidal marsh for all project alternatives. The key hydrologic characteristics of the three alternatives are described below:

Alternative 1

- Pacheco Pond expanded to a capacity of approximately 1241 acre-ft (above 0-ft, NGVD 29)
- flow diverted to proposed tidal marsh from Pacheco Pond through a flap gated culvert structure identical to the existing one at Novato Creek

Alternative 2

- seasonal wetland constructed adjacent to existing Pacheco Pond with a storage volume of approximately 1155 acre-ft (above 0-ft, NGVD 29)
- existing Pacheco Pond and seasonal wetland connected with a 100-ft wide weir, with a crest elevation of 2-ft, NVGD 29
- flow from the seasonal wetland is released to the proposed tidal marsh through a flap gated culvert structure identical to the existing one at Novato Creek

Alternative 3

- for the purposes of this analysis, identical to Alternative 1

UNET Model Description

To evaluate the hydraulics of the existing study basin, as well as the proposed project conditions, the hydraulic modeling program UNET was employed. UNET was developed by the U.S. Army Corps of Engineers, and provides a modeling framework for computing solutions to one-dimensional, unsteady flow problems in complex networks. The choice of using such a model was deemed necessary here due to the dynamic conditions caused by both the fluctuating tide levels in San Pablo Bay, and the rapid changes in water surface elevation expected within Pacheco Pond.

The UNET model requires hydraulic boundary conditions for both the upstream and downstream ends of the study site. For this study, the downstream boundary conditions consisted of the modified, tidal time series measured at the mouth of the Petaluma River as described above. The tidal time series data are shown in Figure 2.

The upstream boundary conditions consisted of inflow storm hydrographs. The storm hydrographs for Pacheco Creek at Pacheco Pond, Arroyo San Jose at Pacheco Pond, and Novato Creek near Highway 37 were obtained from previous studies (2, 5, 6). The hydrologic conditions considered in the analysis consisted of two scenarios. These scenarios, referred to here as A and B, are meant to loosely represent the 10-year and 100-year storm events, respectively. However, a detailed assessment of present and future watershed conditions, coincident storm peak flow analysis, and hydrologic routing characteristics that would more accurately define the expected characteristics of storm hydrographs was beyond the scope of this study. The flow hydrographs for Arroyo San Jose, Pacheco Creek, and Novato Creek for both scenarios A and B are shown in Figures 3, 4, and 5.

Theoretically, there are infinite combinations of phasing between the peak tide and the peak discharge hydrographs. To simplify the analysis, Pacheco Creek and Arroyo San Jose hydrographs were phased to be coincident with the higher high water tidal stage for all model runs. However, the phasing of the Novato Creek hydrograph was varied to investigate the effect of lag times on system. Due to the larger watershed dimensions, the peak discharge from Novato Creek would be expected to lag the Pacheco Pond peak discharges. Novato Creek hydrographs specified at three different lag times relative to the peak hydrograph from the Pacheco Pond watershed: 0-hour lag time (i.e. coincident with the higher high water tide stage and other hydrographs), 6-hour lag time (i.e. 6 hours behind other hydrographs), and 12-hour lag time. The adjustment of phasing was only relevant to the model runs that evaluated the existing conditions, as Pacheco Pond flows are routed away from Novato Creek for all project condition scenarios.

The general modeling strategy was to isolate elements within the drainage system in order to assess their relative effect on peak flows and water surface elevations. A key caveat of this analysis is that the primary consideration should be in comparing *relative* differences between computed peak discharges and water surface elevations. Detailed and consistent surveys of the physical characteristics of Pacheco Pond and Novato Creek are necessary to identify accurate, water surface elevations. These surveys were beyond the scope of this conceptual planning effort. However, *relative* differences in peak water surface elevations and flowrates between the alternative conditions assessed in this analysis are fairly insensitive (less than 0.25 feet) to the small changes in absolute geometric conditions (e.g. plus or minus 1-foot of vertical difference in invert elevations). Thus, the relative changes between existing and project alternative conditions can be used to assess project performance and impacts.

Four cases were considered. The first consisted of modeling the existing Pacheco Pond-Novato Creek system. The second case considered only Novato Creek, without contributing flows from Pacheco Pond, and the third and fourth cases considered only the isolated Pacheco Pond. These third and fourth cases were used to evaluate the effects and differences between Alternatives 1 & 3, and 2, on pond hydraulics. The primary assumption in the third and fourth cases is that the entire flow into Pacheco Pond will be rerouted to the proposed tidal marsh. Table 1 outlines the modeling conditions for each case.

Table 1. UNET Model Conditions

<table>
<tr><th>Case</th><th>Model Conditions</th></tr>
<tr><td>Existing Novato Creek and Pacheco Pond Network - Evaluates the interaction between Pacheco Pond and Novato Creek for existing conditions</td><td>Boundary Conditions
Arroyo San Jose: Scenario A and B Hydrographs
Pacheco Creek: Scenario A and B Hydrographs
Novato Creek: Scenario A and B Hydrographs; 0, 6, 12 hour lag
San Pablo Bay: Truncated/amplified tide series
Model Elements
Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to Novato Ck
100-ft wide lateral weir at 5.6-ft, NGVD 29 for pond overflow to Leveroni Property
1000-ft wide lateral weir at 6.7-ft, NGVD 29 for pond overflow
300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMKV wetlands restoration site downstream of BMK residential development.</td></tr>
<tr><td>Project Conditions on Novato Creek- Evaluates only Novato Creek while considering influence of added restored tidal prism downstream of BMK residential development. The connection with Pacheco Pond is removed from the model.</td><td>Boundary Conditions
Novato Creek: Scenario A and B Hydrographs; 12 hour lag
San Pablo Bay: Truncated/amplified tide series
Model Elements
right bank levee removed downstream of BMK residential development
right bank floodplain expanded laterally by 1000-ft downstream of BMK residential development to reflect opportunity for overflow into restored tidal marsh
450-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek.</td></tr>
<tr><td>Pacheco Pond Configuration for Alternative 1 & 3 - Evaluates an expanded Pacheco Pond with a flap gate outlet to the tidal marsh</td><td>Boundary Conditions
Arroyo San Jose: Scenario A and B Hydrographs
Pacheco Creek: Scenario A and B Hydrographs
San Pablo Bay: Truncated/amplified tide series
Model Elements
Pacheco Pond expanded
Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh</td></tr>
<tr><td>Pacheco Pond Configuration for Alternative 2 - Evaluates Pacheco Pond with an adjacent seasonal marsh storage area, flow controlled by weir and flap gate structure</td><td>Boundary Conditions
Arroyo San Jose: Scenario A and B Hydrographs
Pacheco Creek: Scenario A and B Hydrographs
San Pablo Bay: Truncated/amplified tide series
Model Elements
Additional 650-acre storage area attached to Pacheco Pond to simulate constructed seasonal wetland
100-ft wide inline weir to control flow from pond to seasonal marsh
Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh</td></tr>
</table>

Model Results

The UNET model results of primary interest are the effects of the proposed tidal restoration on the stage within Pacheco Pond and Novato Creek. With respect to the former, comparison between the stage hydrographs within the existing pond (Figs. 6 and 7) and those of Alternatives 1 & 3, and 2 (Figs. 8 and 9), show that the proposed changes will substantially reduce peak water surface elevations within Pacheco Pond (Table 2). This reduction in Pacheco Pond elevations will have a positive benefit on Ignacio Business Park drainage conditions that are presently aggravated by high stages within Pacheco Pond. The magnitude and extent of this improvement to local storm drainage conditions, however, was not quantified in this analysis.

Table 2. Peak Water Surface Elevations in Pacheco Pond (ft, NGVD 29)

Case	**Scenario A**	**Scenario B**
Existing	6.4	7.6
Alternative 1 & 3	4.5	7.2
Alternative 2	4.6	6.3

Also of interest are the effects of the proposed project on stages within Novato Creek. Under the project alternatives being considered for the Bel Marin Keys tidal wetland restoration, all flow from Pacheco Pond will be diverted away from Novato Creek and routed through new drainage structures into the proposed tidal marsh. To examine the effect of this diversion, stage hydrographs at select locations along Novato Creek are presented in Figures 10 and 11, for scenarios A and B, respectively. The locations chosen include the upstream limit of the model at Highway 37 bridge (CS 10), at the existing confluence of Pacheco Pond with Novato Creek (CS 8), and just downstream of the lower Bel Marin Keys navigational lock (CS 4).

The stage hydrographs shown in Figures 10 and 11, suggest that peak water surface elevations within Novato Creek are controlled primarily by tidal fluctuations. That is, the effects of diverting Pacheco Pond flow, in addition to the added tidal prism created by the constructed tidal marsh, do not substantially change the peak water surface elevations between existing and project conditions. The changes that do occur are a negligible drop (less than 0.1 foot) in peak stage when Pacheco Pond flow is diverted.

References:

1. Jones & Stokes Associates Inc., 1998 (December), "Hamilton Army Airfield Wetland Restoration, Final EIR/EIS" California State Coastal Conservancy, and U.S.A.C.E, S.F.

2. Philip Williams & Associates Ltd., 1998 (October), "Appendix E: Hamilton Base Realignment & Closure, Wetland Conversion Alternative: Airfield Panhandle Flood Assessment", Prepared for IT Corp.

3. San Francisco International Airport's Airfield Development Engineering Consultant (ADEC). 2000. (1) Text file, EXCEL spreadsheet with bathymetry and tide data; (2) digital orthometric photography; (3) LiDAR topography, vertical

datum NGVD 1929, horizontal datum NAD 1983. Provided by Moffit Nichol Engineers.

4. Gonzalez and Oberkamper Civil Engineers, Inc., 1975. “Appendix IV Drainage Analysis Ignacio Industrial Park Marin County, California”. Prepared for Madrone Associates Environmental Consultants. “Final Environmental Impact Report Ignacio Industrial Park, Unit 3”.

5. U.S. Army Corps of Engineers, San Francisco District, 1987, "Hydrologic Engineering Report, Novato Creek and Adjacent Streams", City of Novato, Marin County, California.

6. CSW/Stuber-Stroeh Engineering Group Inc., 1996 (January), "Bel Marin Keys V Master Storm Water Management Plan", Prepared for the Presidio Group.

7. Towill, Inc. 1996. “Hydrographic Survey of Novato Creek performed on July 31 and August 1 for the Bel Marin Keys Community Services District.” San Francisco, CA.

8. San Francisco District, Corps of Engineers, 1984. “San Francisco Bay, Tidal Stage vs. Frequency Study,” San Francisco, CA.

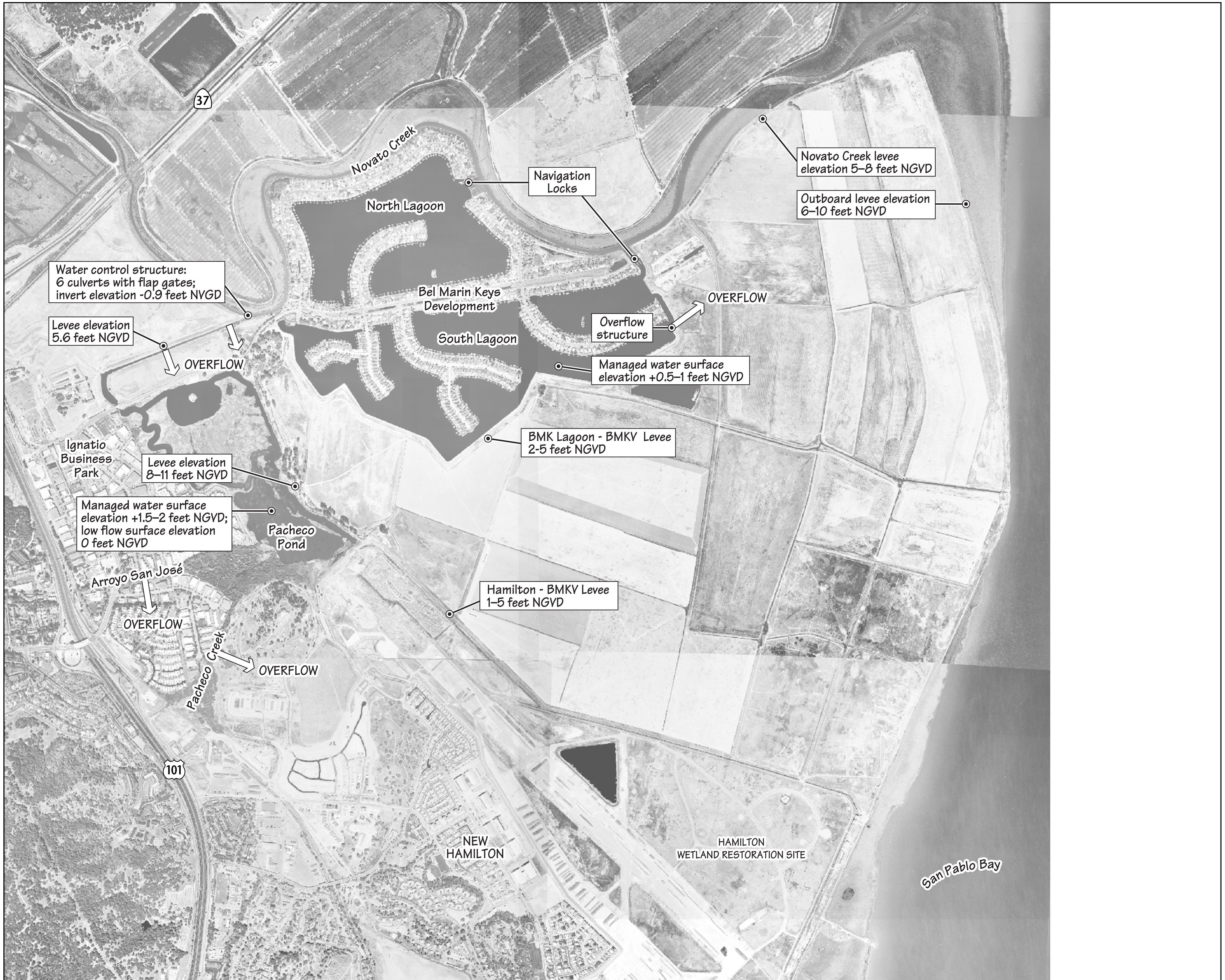
9. Federal Emergency Management Agency (FEMA), 2002. “Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix D: Guidance for Coastal Flooding Analyses and Mapping”, www.fema.gov/mit/tsd/dl_cgs.htm.

10. Federal Emergency Management Agency (FEMA), 2002. “City of Novato, California, Flood Insurance Rate Map Community-Panel Number 060178 0005 B”, Map Revision Date April 3, 1984.

11. Charles D. Anderson, Katherine M. Oven, Christy Chung, 2000. “Surf’s Up – or Tide Cycles During Storm Events.” Spring 2000 Floodplain Managers Association Conference, San Diego, CA.

12. U.S. Army Corps of Engineers, Sacramento District. 1993. “Coyote and Berryessa Creeks, California Final General Design Memorandum”.

Figure 1
Hydrologic Setting at the Project Site



Jones & Stokes nhc

02002.02-002 3/13/02

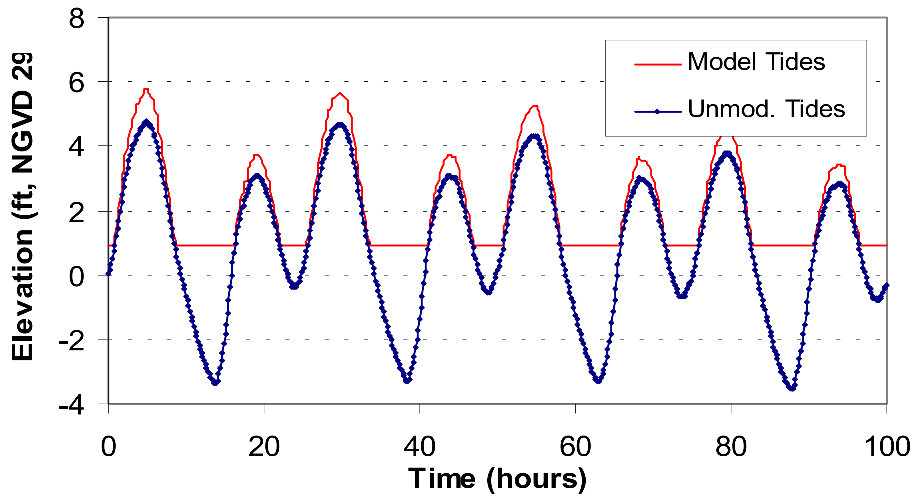


Figure 2. Unmodified tide series, and tide series used in UNET model

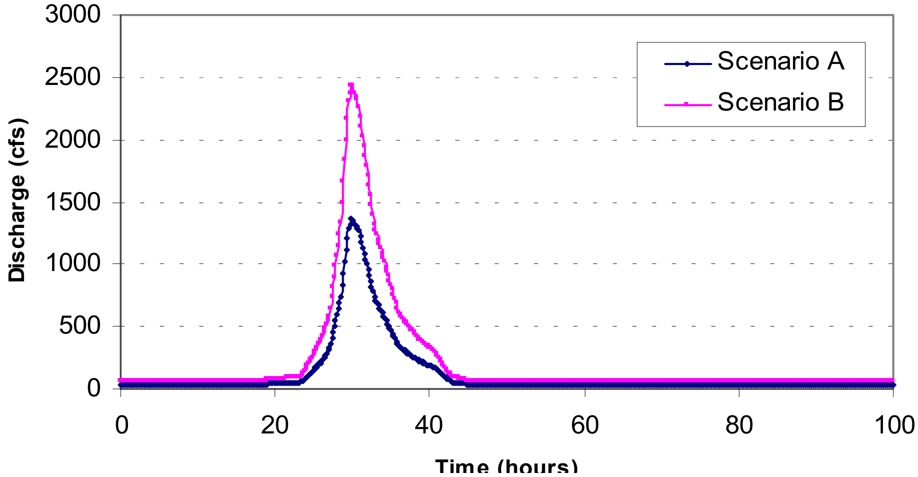


Figure 3. Arroyo San Jose Input Hydrographs

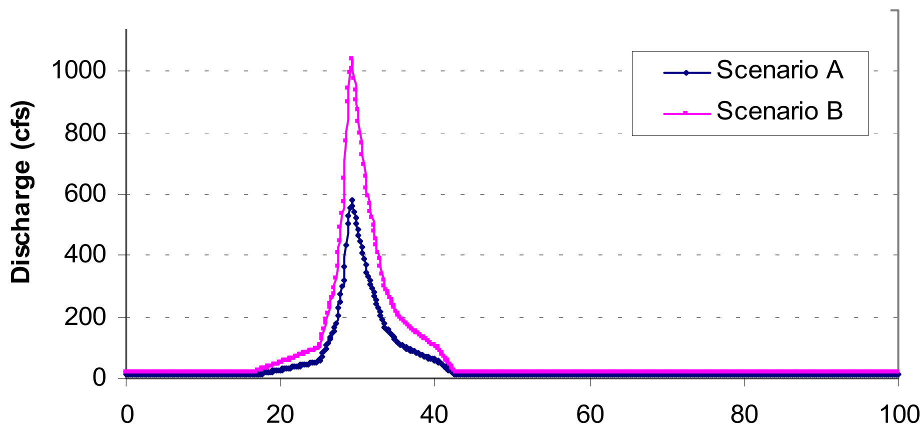


Figure 4. Pacheco Creek Input Hydrographs

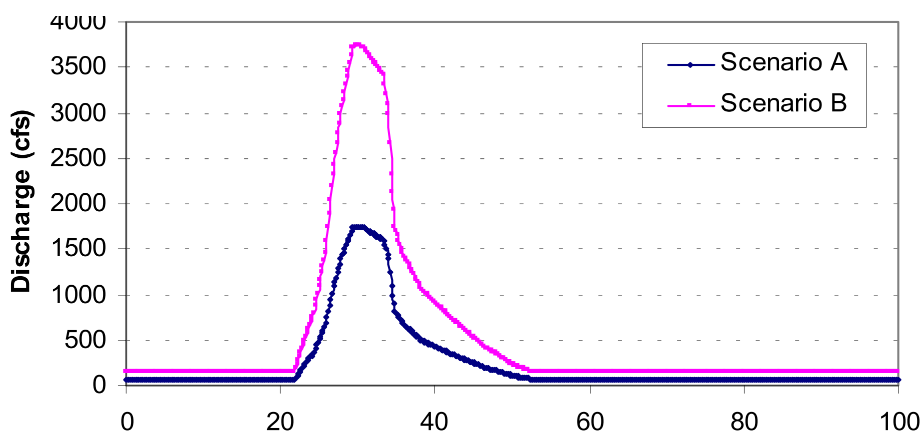


Figure 5. Novato Creek Input Hydrographs (0-hour lag)

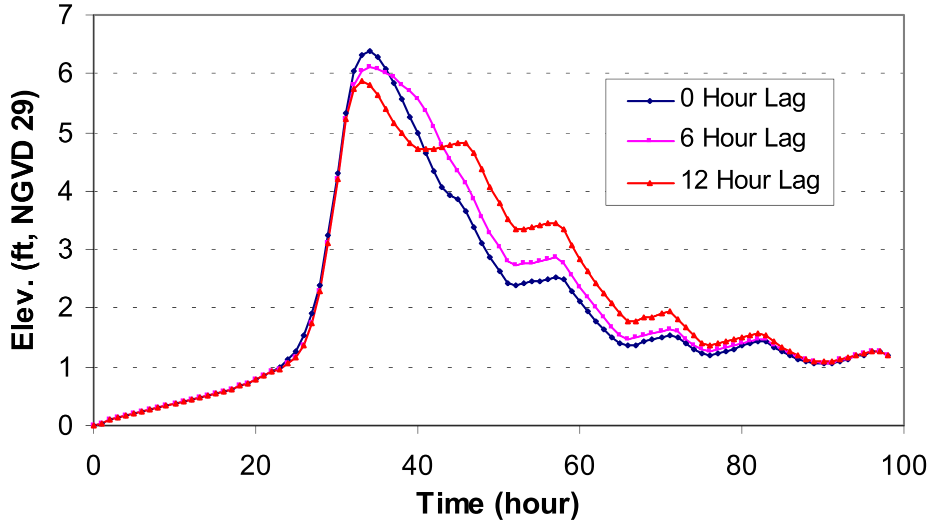


Figure 6. Pacheco Pond water surface elevations, existing conditions, Scenario A

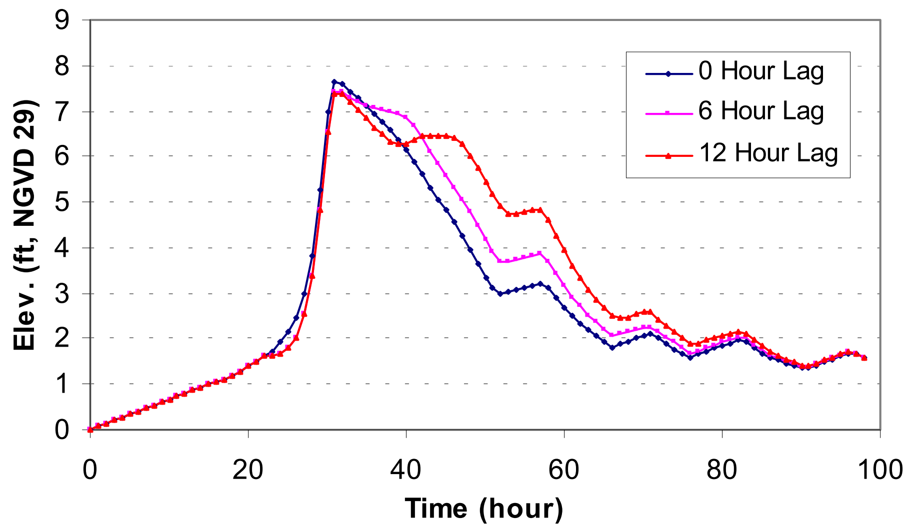


Figure 7. Pacheco Pond water surface elevations, existing conditions, Scenario B

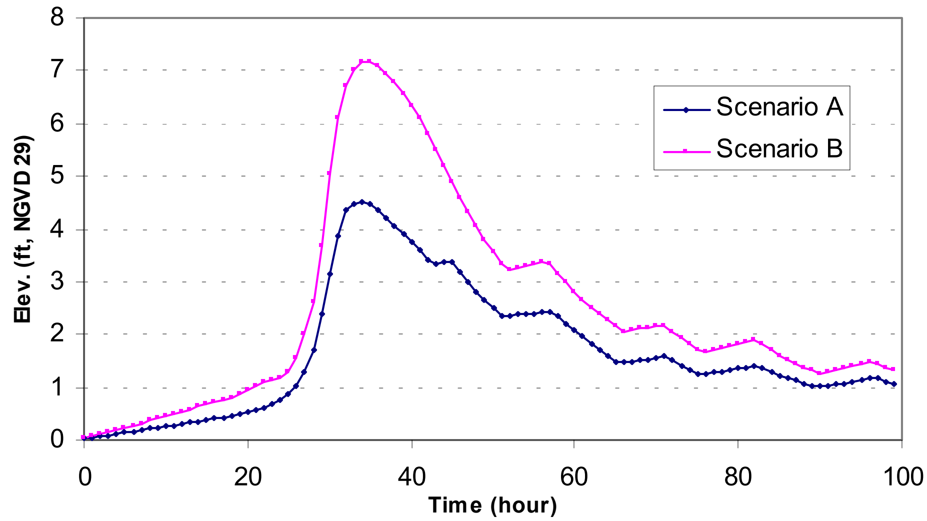


Figure 8. Pacheco Pond water surface elevations, Alternatives 1 & 3

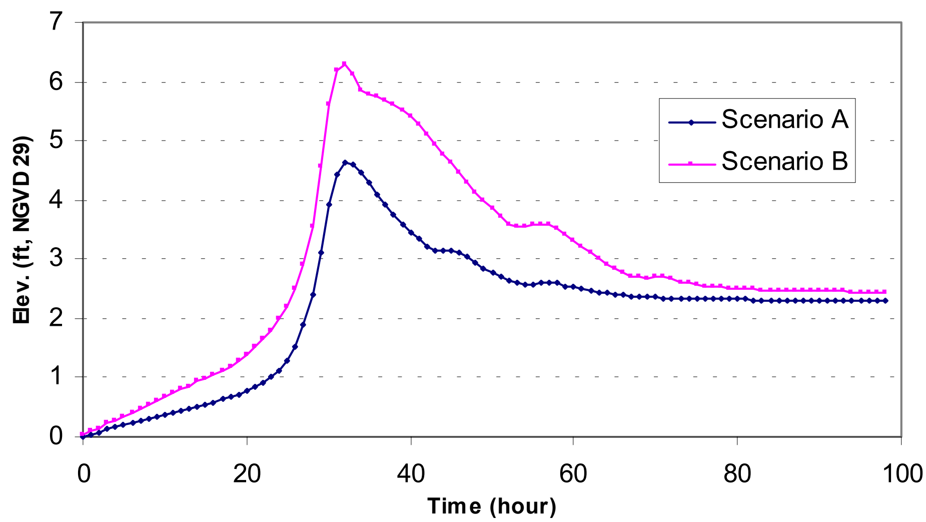


Figure 9. Pacheco Pond water surface elevations, Alternative 2

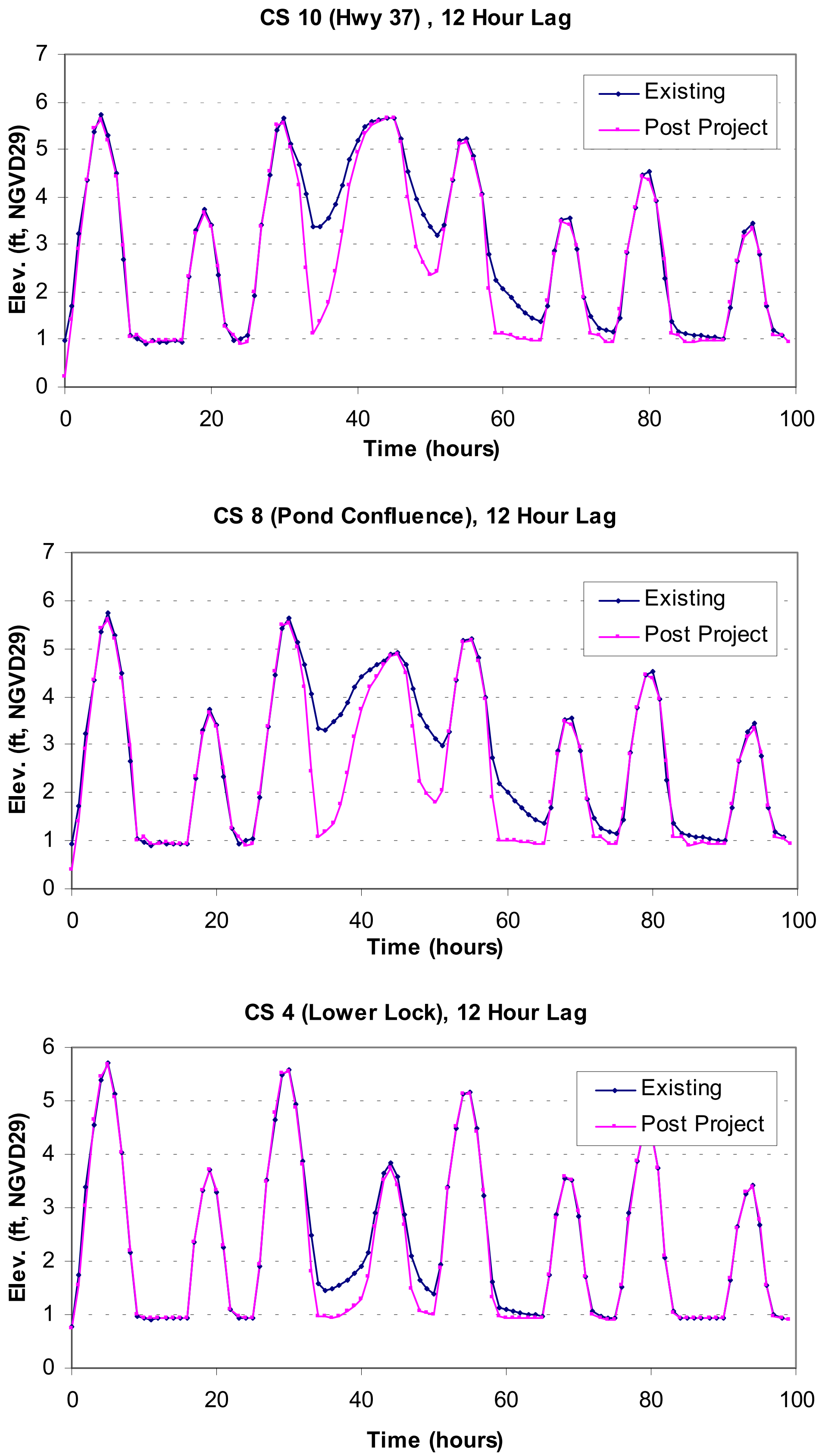


Figure 10. Stage hydrographs at select locations along Novato Creek, Scenario A

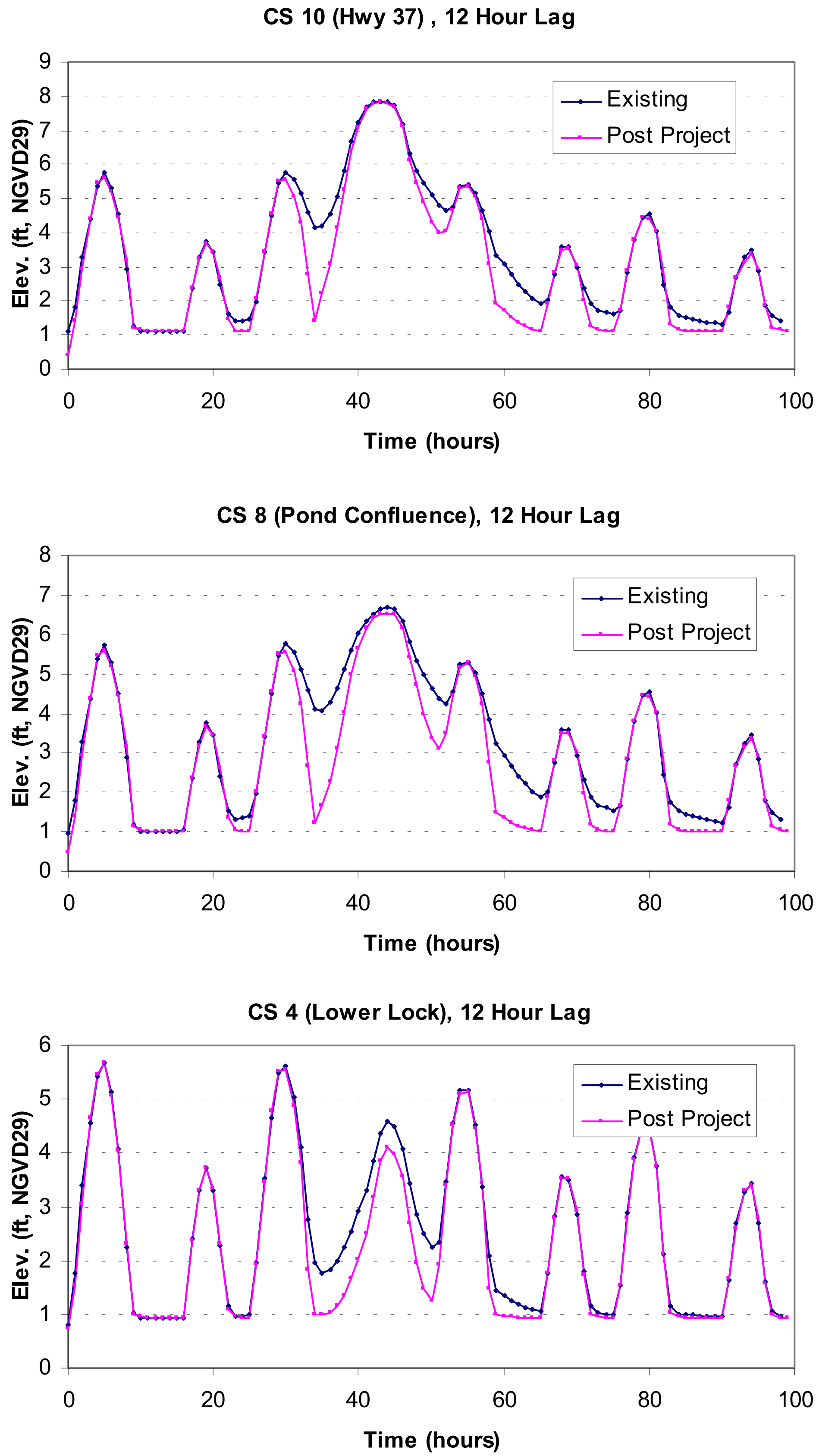


Figure 11. Stage hydrographs at select locations along Novato Creek, Scenario B

Bel Marin Keys Unit V Expansion of the Hamilton Wetland Restoration Project

Hydraulic Routing Analysis

Purpose

This document presents a hydraulic impact investigation performed by Northwest Hydraulic Consultants (**nhc**) of the proposed Bel Marin Keys tidal marsh restoration project on Pacheco Pond and Novato Creek. The purpose of the study was to quantify the relative hydraulic effects of the proposed project on Pacheco Pond and on Novato Creek from the Pacheco Pond outlet to San Pablo Bay.

This document describes supplementary hydrologic and hydraulic analyses initially presented in the technical memorandum entitled "Hydrologic and Hydraulic Modeling Assessment of Existing and Project Alternatives at Bel Marin Keys," dated April 18, 2002 (**nhc**, 2002a). Supplementary information presented in the following sections of this report includes a refinement of the geometric conditions for Alternative 2, as well as an assessment of additional scenarios for evaluating the effects of Pacheco Pond on existing and project alternative conditions on Novato Creek flood dynamics. Computed time histories of channel velocity, flow rate, and water surface stage for several hydrologic scenarios are also presented in this report.

Background

Over the last two centuries, hydrologic conditions in the Novato Creek watershed below Highway 37 have varied dramatically due to changes in land use practices and engineered modifications to the land surface. These modifications include the construction of flood protection levees, the development of Pacheco Pond as a flood detention system, and the rerouting of drainage channels and installation of flap gates on Simmons Slough and Pacheco Pond. This has decreased the tidal prism of lower Novato Creek significantly, and has resulted in accretion of the channel. The reduction in channel size due to accretion has decreased the flood capacity of the system and has proved undesirable for navigation. The creek is constantly evolving toward a smaller width and depth consistent with the reduced tidal prism. Actions to counter the effects of channel accretion include the periodic surveying and raising of levees along the north side of Novato Creek from Highway 37 to the mouth and dredging of Novato Creek downstream of its confluence with Pacheco Pond.

Hydraulic Setting

Novato Creek is the principal drainage in the vicinity of the project site and has an approximate total watershed area of 44 square miles. Two smaller drainages, Arroyo San Jose (drainage area of 5.4 square miles) and Pacheco Creek (drainage area of 1.9 square miles) discharge into Pacheco Pond. The pond ultimately drains into Novato Creek by means of six 4-foot by 4-foot flap gates. The flap gates open when the stage in Pacheco Pond exceeds the stage in Novato Creek and the invert of the flap-gate culvert, which is approximately -0.86 feet NGVD 29. In addition, Simmons Slough drains lowlands to the north of Novato Creek and discharges into Novato Creek through a flap gate culvert downstream of the Pacheco Pond culvert.

The Bel Marin Keys Community Service District (CSD) operates two locks that provide recreational vessel access to the North and South Lagoons of the community. The North Lock facility includes three tainter gates used for lagoon flushing purposes. Managed releases from the lagoons are conducted by the CSD to promote channel scour in Novato Creek to improve navigability of the tidally influenced portion of Novato Creek. A location map showing the project site and adjacent areas is provided in Figure 1.

Downstream of Highway 101, the geometry of Novato Creek is characteristic of tidally influenced channels throughout San Francisco Bay, and is composed of a consolidated bay mud main channel with tidal salt marsh benches. The slope of the lower channel is relatively mild, with a general longitudinal slope of

0.002 ft/ft between Highway 101 and Diablo Avenue to approximately 0.0001 ft/ft near the mouth. These slopes result in subcritical flows throughout the lower reach, even during storm events. However, critical and supercritical flows may occur in discrete locations during low tide conditions.

Novato Creek transitions from channel-control to tidal-control within this reach, as the slope of the creek reduces and the creek elevations come within San Pablo Bay tidal range. Tidal effects from San Pablo Bay become apparent and influence the stage of the creek, as the creek stage rises and falls with the tidal stage in San Pablo Bay. The location of the transition point from channel- to tidal-control varies with the magnitude of terrestrial inflows and tide stage characteristics.

Channel conveyance, and thus discharge capacity, in lower Novato Creek is directly related to the tide level. Since both the tide stage and inflows to Novato Creek vary with time, the channel conveyance also varies in time. Furthermore, since conveyance is a function of both terrestrial inflow and tide, peak stages in lower Novato Creek do not necessarily occur during the peak flow. The time-dependant effects of the changing inflows and tide (referred to as hydraulic boundary conditions) necessitate the application of a dynamic model to properly simulate the physical processes of tidally influenced, unsteady creek flow.

Although tidally influenced systems are unsteady by nature, steady-state hydraulic models, or models in which the boundary conditions do not vary with time, can be used to conservatively estimate water surface profiles and discharge in tidal channels. Steady-state models are simpler to operate and were more commonly applied prior to the advent of modern personal computers. Using HEC-2, a steady-state model developed by the Corps of Engineers, FEMA calculated a maximum channel conveyance capacity downstream of Highway 37 of 2,500 cfs (FEMA, 1989). It is worth noting that this is significantly less than the effective 10-year peak discharge of 3,420 cfs discharge published in the City of Novato FIS (FEMA, 1989).

The 1984 City of Novato Flood Insurance Rate Map published by FEMA indicates a nearly flat water surface coincident with the peak 100-year tidal stage in the lower reach of Novato Creek, revealing the dominance of tidal flooding over terrestrial flooding in Novato Creek downstream of Highway 37 for the one percent annual exceedance probability (100-year recurrence interval) flood. These predicted tide stages are based on tide stage frequency analyses conducted by the Corps. The 1989 City of Novato FIS rounds the Corps tidal flood stage of 6.5 feet NGVD 1929 to 7 feet NGVD 29 as per FEMA mapping guidelines (FEMA 2002).

Tides in San Pablo Bay follow a mixed semidiurnal cycle, with two high and two low tides, of differing heights, occurring in a single day. Due to geographic and hydrodynamic complexities, mean tide levels vary throughout the San Francisco Bay. Tide cycles in San Pablo Bay lag those at the Golden Gate Bridge by as much as 75 minutes. Peak tide levels in the vicinity of Novato Creek are 6.0 ft NGVD 29 for the 10-year tide and 6.5 ft NGVD 29 for the 100-year tide (San Francisco District, 1984).

Storm events may lead to higher tidal stages than those predicted by gravitational forces for a variety of reasons. First, low barometric pressures associated with significant storms can cause an increase in tidal stage, as the ocean's surface level increases in response to the barometric low. Second, strong wind shear may push water towards land, leading to the phenomenon of a storm surge. Third, increases in large-scale regional runoff from the Sacramento and San Joaquin watersheds, as well as contributions from San Francisco Bay watersheds, can limit the low tidal excursion of normal tidal cycles. San Pablo Bay, for instance, is filled mainly by regional runoff and runoff from the Sacramento and San Joaquin River systems (Anderson et al., 2000).

Model Selection

The hydraulic modeling program UNET was utilized to evaluate the existing hydraulic conditions of lower Novato Creek, as well as evaluate the hydraulic conditions for the proposed project conditions. UNET is a one-dimensional model, developed by the U.S. Army Corps of Engineers, and provides a modeling framework for computing solutions to unsteady flow problems in channel networks. UNET also provides routines for evaluating levee overflow to floodplain storage, stage-discharge routing of bridges, culverts and flap-gate culverts, and routing hydraulic linkages between main channel conveyance and overbank floodplain storage. These features make UNET an ideal tool for simulating the dynamic conditions within Novato Creek, as fluctuating tide levels in San Pablo Bay and the time dependent nature associated with storm hydrographs result in spatially and temporally variable hydraulic conditions. In addition, the relatively confined flow conditions exhibited by the Pacheco Pond-Novato Creek system are conducive to a one-dimensional analysis where connections between the main channel and storage areas are easily defined by discrete channel links. Finally, the use of UNET in a tidal environment is consistent with Corps and FEMA Guidelines (FEMA 2002). FEMA approves the use of one-dimensional unsteady flows in channel networks where flow reversals may occur and flood storage capacity must be considered.

Study Limits

The study domain used to assess the impacts of the proposed project alternatives extends from the mouth of Novato Creek upstream approximately 4 miles to the downstream face of the railroad bridge near Highway 37. Subcritical reaches are subject to downstream control, meaning that the hydraulic characteristics of a given cross section can affect stages that occur upstream. However, the distance that this effect propagates upstream is limited by channel slope and friction. This implies that if no increase in water surface elevation is calculated at the upstream study limit, then there will not be any increase in channel stage upstream of the study limit.

UNET Model Structure

UNET is an open channel network model that requires geometric data, friction coefficients, and boundary conditions as input. Using these input variable, the model solves the one-dimensional unsteady flow equations and calculates the flow magnitude and direction, water surface elevation at each cross section, and the storage characteristics of each storage area. For the impact analyses, the model geometry and boundary conditions are based on existing data.

Geometry

The study reaches include Pacheco Pond, Novato Creek, and the Bel Marin Keys V site. Network model geometries were developed by **nhc** from existing Light Detection and Radar (LiDAR), levee, and bathymetric surveys (Towill 1996). Since the model is designed to identify relative changes in hydraulic characteristics due to project features, several simplifying assumptions were made regarding Novato Creek's and Pacheco Pond's connections to adjacent areas. These include the assumption that flow from Novato Creek could only pass to the BMK V site and from Pacheco Pond through the flap gate connection. This allows for easily tracking changes in water surface elevations in Novato Creek due to project modifications by not simulating overtopping of levees into other adjacent areas such as the Antenna Fields north of Novato Creek. Furthermore, this assumption provides a conservative means to identify the project features' influence on water surface elevations.
The volume of flow overtopping the levee separating Pacheco Pond and the BMKV (at an elevation between 6 and 7 feet NGVD29) was investigated during initial sensitivity analyses. Approximately 14.4 acre-feet were calculated to flow over the levee into the BMKV site for the existing conditions geometry in Inflow Scenario A. This volume is approximately 0.6 percent of the inflowing volume to Pacheco Pond during Inflow Scenario A. Based on this analysis, weir flow over the levee was determined to be negligible with respect to the overflow volume's potential to increase flood stages.

Four geometric scenarios were developed to identify impacts on hydraulic characteristics along Novato Creek. These scenarios are summarized listed in Table 1 and graphically depicted in network schematic diagrams on Figure 2.

Water surface elevation and storage in Pacheco Pond and the Bel Marin Keys V site were simulated as storage areas in the UNET model. A lateral weir between Novato Creek and the Bel Marin Keys V site was defined to compute overflow and storage on the project site for existing conditions. From the existing LiDAR and survey data, cross sections, storage area stage-volume relationships, and lateral weir characteristics were defined. Using the LiDAR data, the Pacheco Pond storage volume between 0 and 7 feet NGVD was calculated to be 880 ac-ft. This volume is same as reported in Appendix IV in the Final Environmental Impact Report for Ignacio Industrial Park, Unit 3 (Madrone 1975) between 0 and 7 feet

MSL. Due to the ongoing changes in the terrain resulting from subsidence and channel evolution, it is not possible, nor is it necessarily required, to define present day geometric conditions precisely to identify the hydraulic impacts of the project on Novato Creek and Pacheco Pond.

The cross sections used in the model include the subtidal channel of the creek, adjacent marsh floodplain, and the existing levee structures. A cross section layout is shown in Figure 1. Top of levee surveys completed in 1996 (Towill 1996), indicate that the levee crest between Novato Creek and the Bel Marin Keys V site dips to an elevation of approximately 5.6-ft, NGVD 29, at a point approximately 1000 feet downstream from the Bel Marin Keys South Lagoon navigation lock. Overtopping of this levee was observed by Bel Marin Keys residents during the February 1998 flood event. Levee surveys of the Pacheco Pond outlet channel reveal low points at 5.6 and 6.7 ft NGVD 29. Based on these data, the baseline geometric condition considers the following features:

- Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from Pacheco Pond to Novato Ck;
- 100-ft wide lateral weir at 5.6-ft, NGVD 29 for pond overflow into Novato Creek on Leveroni Parcel
- 1000-ft wide lateral weir at 6.7-ft, NGVD 29 for pond overflow into Novato Creek on Leveroni Parcel;
- 300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMKV site approximately 1000 feet downstream of BMK community.

Table 1. Novato Creek Geometric Scenarios

Scenario	Model Conditions
Scenario 1: Existing Novato Creek and Pacheco Pond Network - **Evaluates the interaction between Pacheco Pond and Novato Creek for existing conditions**	Model Elements • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from Pacheco Pond to Novato Ck;** • **100-ft wide lateral weir at 5.6-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **1000-ft wide lateral weir at 6.7-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMKV site approximately 1000 feet downstream of BMK community**
Scenario 2: No Pacheco Pond Outlet to Novato Creek and a Design Breach along BMKV -	Model Elements • **Pacheco Pond disconnected from Novato Creek;** • **right bank levee removed downstream of BMK Development** • **right bank floodplain expanded laterally by 1000-ft downstream of BMK Development to reflect opportunity for overflow into restored tidal marsh** • **600-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek.**
Scenario 3: Pacheco Pond Outlet to Novato Creek and a Design Breach -	Model Elements • **100-ft wide lateral weir at 5.6-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **1000-ft wide lateral weir at 6.7-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh** • **right bank levee removed downstream of BMK Development** • **right bank floodplain expanded laterally by 1000-ft downstream of BMKV swale to reflect opportunity for overflow into restored tidal marsh** • **600-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek.**
Scenario 4: No Pacheco Pond Outlet and No Design Breach along BMKV -	Model Elements • Connections between Pacheco Pond and Novato Creek Removed.

Hydraulic parameters in Pacheco Pond were estimated from geometric Scenarios 1, 3, 5, and 6. In Alternatives 1, 2, and 3 Pacheco Pond drains to the BMKV site and the outlet to Novato Creek is closed. Alternatives 1 and 3 were simulated by Geometric Scenarios 5 and Alternative 2 was simulated by Geometric Scenario 6. These scenarios are summarized in Table 2.

Scenario	Model Conditions
Scenario 5: Pacheco Pond Configuration for Alternatives 1 and 3 - **Evaluates an expanded Pacheco Pond with a flap gate outlet to the tidal marsh**	Model Elements • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from Pacheco Pond to tidal marsh;** • **Pacheco Pond expanded to increase the pond surface area by 74 ac.**
Scenario 6: Pacheco Pond Configuration for Alternative 2 - **Evaluates an expanded Pacheco Pond with an adjacent seasonal marsh storage area, flow controlled by weir and flap gate structure**	Model Elements • **100 -ft weir controls flow from Pacheco Pond to seasonal wetland;** • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from seasonal wetland to tidal marsh** • **Seasonal wetland surface area 135 ac** • **Pacheco Pond surface area expanded by 32 ac.**

Boundary Conditions

Boundary conditions were developed at the upstream and downstream study limits. Two inflow scenarios were modeled loosely representing the 10- and 100-year flow events for existing conditions. Hydrologic Scenarios A and B use published 10-year and 100-year flood event hydrographs, respectively, from two previous Corps of Engineers studies (Corps of Engineers 1987, PWA 1998).

Tide measurements taken at the mouth of the Petaluma River were utilized to develop time series of tidal stage hydrographs at the mouth of Novato Creek. These data, completed as part of the San Francisco Airport runway expansion dredge material disposal studies, consist of tidal stage measurements recorded at 10-minute increments for approximately one month duration (14 June - 17 July 2000). Previous studies of Novato Creek indicate negligible differences between Novato Creek and Petaluma River tidal stage characteristics (PWA, 1998). To conservatively estimate tidal conditions during flood events, the tide data were modified in two ways to reflect extreme tidal conditions that occur during significant flood events. The first modification was to increase the observed peak tidal stage by one foot to reflect extreme high tides due to low atmospheric pressure and wind setup in the region. This is equivalent to coincident tidal stage boundary conditions frequently used by the Corps of Engineers and the FEMA for flood control design or flood hazard mapping studies on tidally influenced streams and rivers in the San Francisco Bay Area. The resulting peak tide was calculated to be 5.75 ft NGVD 29, 0.25 feet lower than the 10-year peak tide. The second modification was to truncate the low tide elevation at the mean tide level to represent limits on low tide excursion due to extreme regional, basin-wide runoff conditions (Anderson et al, 2000). The resulting tidal boundary condition is shown in Figure 3.

Theoretically, there are infinite phasing combinations between the peak tide elevation and the peak discharge hydrographs. To simplify the analysis, Pacheco Creek and Arroyo San Jose hydrographs were phased to be coincident with the higher high water tidal stage for all model runs. However, the phasing of the Novato Creek hydrograph was varied to investigate the effect of lag times on system. Due to the larger watershed dimensions, the peak discharge from Novato Creek would be expected to lag the Pacheco Pond peak discharges. Novato Creek hydrographs were developed using three different lag times relative to the peak hydrograph from the Pacheco Pond watershed: 0-hour lag time (i.e. coincident with the higher high water tide stage and other hydrographs), 6-hour lag time (i.e. 6 hours behind other hydrographs), and 12-hour lag time. The adjustment of phasing was only relevant to the model runs that evaluated the existing conditions, as Pacheco Pond flows are routed away from Novato Creek for all project condition scenarios.

Loss Coefficients

Channel friction is expressed in UNET using Manning's equation. The Manning's roughness coefficient was set at 0.02 for the subtidal channel and 0.04 for the salt marsh benches. These values were adopted from calibrated UNET models of Sonoma Creek developed as part of the mitigation planning for the San Francisco Airport runway expansion studies.

Model Scenarios

Four geometric scenarios were run for each of the hydrologic flow scenarios to assess project impacts on Novato Creek. Pacheco Pond was connected to Novato Creek in scenarios 1 and 3. Two additional geometric scenarios of Pacheco Pond (scenarios 5 and 6) were defined to evaluate the impacts to Pacheco Pond water surface elevations by the project alternatives. In these scenarios the flap gate connection between Pacheco Pond and Novato Creek was closed, thus identifying the effects of diverting all flow to Bel Marin Keys V project site. However, it should be noted that a new water management scenario envisioned by the project includes dual use of the existing and new outlets to enhance water quality in Pacheco Pond. Project Alternatives 1 and 3 were modeled as one scenario and Alternative 2 was modeled as a separate scenario. The conditions for Pacheco Pond draining directly to the Bel Marin Keys V site are modeled as Scenarios 5 and 6, respectively. The characteristics of the geometric model scenarios are summarized in Table 2. Schematic diagrams of the hydraulic connections and storage areas are shown in Figure 2.

Table 2. Geometric Model Scenarios

Scenario	Description
1	Existing conditions Novato Creek connected to Pacheco Pond. No design breach between Novato Creek and BMKV
2	Alternative 2 No connection between Novato Creek and Pacheco Pond Design breach between Novato Creek and BMKV
3	Novato Creek connected to Pacheco Pond. Design breach between Novato Creek and BMKV
4	No connection between Novato Creek and Pacheco Pond No design breach between Novato Creek and BMKV
5	No connection between Novato Creek and Pacheco Pond Pacheco Pond expansion Pacheco Pond outlet to BMKV as described in Project Alternatives 1 and 3
6	No connection between Novato Creek and Pacheco Pond Pacheco Pond connected to expanded pond and seasonal wetland as described in Revised Alt. 2 Seasonal Wetland outlet to BMKV as described in Revised Alternative 2

Model Results

Summarized below are the model results for the hydraulic routing analyses. Values presented in the results section are intended for comparison purposes to identify relative changes in hydraulic parameters between project elements (i.e. Pacheco Pond removal and/or design breach). Comparisons of water surface stage, velocity, and flow were made between Geometric Scenarios for a each flow condition.

Project Impacts to Novato Creek Stage -The project's impact on stage was evaluated by reviewing time series of computed stage data at three locations along Novato Creek; the proposed design breach location (Section 2.8), downstream of the Pacheco Pond outlet (Section 8 ds), and at the upstream model cross section immediately downstream of Highway 37 (Section 10). Scenario 1, which is equivalent to existing conditions on Novato Creek with a flap gate connection to Pacheco Pond and no design breach to the Bel Marin Keys V site, was used as the baseline condition from which comparisons with Scenarios 2 through 4 were made. The comparisons are described below.

- **Impact of levee breach** - Addition of the design breach to the baseline condition modeled in Scenario 3 produces negligible changes in water surface elevations (i.e. 0.25 feet or less) at

Sections 2.8, 8 ds, and 10. The time series histories are shown on Figures 4 and 5 for Inflow Conditions A and B, respectively.

- **Impact of rerouting Pacheco Pond connection to Bel Marin Keys V project site** – Removal of Pacheco Pond in Scenario 2 reduced the flow into Novato Creek and increased the magnitude of flow recession during ebb tides. A small (<0.25 foot) reduction in peak water surface elevation was also computed at all points on Novato Creek. These results are summarized in Table 3.

The computed stage for Scenarios 1 and 3, Pacheco Pond connected to Novato Creek, are similar at Sections 2.8, 8 ds, and 10 as are Scenarios 2 and 4, without Pacheco Pond connected to Novato Creek. The rapid stage recession computed in Scenarios 2 and 4 results from the reduced flow into Novato Creek from Pacheco Pond. These observations hold true for both Inflow Condition A and B.

Table 3. Summary of Maximum Stages

Scenario	Flow Condition A			Flow Condition B		
	Sec 2.8 Stage, ft	Sec 8 d/s Stage, ft	Sec 10 Stage, ft	Sec 2.8 Stage, ft	Sec 8 d/s Stage, ft	Sec 10 Stage, ft
1	5.69	6.13	6.55	5.69	7.26	8.09
2	5.64	6.12	6.54	5.69	7.00	7.98
3	5.64	6.12	6.54	5.64	7.13	8.03
4	5.69	6.13	6.52	5.68	7.04	7.99

Project Impacts to Novato Creek Velocity - Impacts due to Pacheco Pond and the design breach on channel velocity were assessed in a similar manner as the stage impacts, and are summarized below.

- **Impact of levee breach** – The levee breach connection to the restored tidal wetland in Scenarios 2 and 3 shows a large change in the computed velocity time series at Section 2.8, located immediately downstream of the levee breach, when compared with Scenario 1. Higher magnitude ebb and flood velocities are created by increasing the tidal prism of the restored tidal wetland and connecting this tidal prism to Novato Creek. The levee breach has no appreciable effect on velocity magnitudes upstream of the design breach at Sections 8 ds and 10. A summary of the peak velocities calculated for each scenario is provided in Table 4. Time series are shown in Figure 6 and 7 for flow scenarios A and B, respectively.

- **Impact of removing Pacheco Pond** – Removal of Pacheco Pond flood flows to Novato Creek has a negligible impact of peak velocities (less than 0.5 fps) at Sections 8 and 10. The velocity time series at these locations indicate a more rapid recession of velocities when Pacheco Pond flows are removed from the Novato Creek system.

Table 4. Summary of Maximum Velocity

Scenario	Flow Condition A			Flow Condition B		
	Sec 2.8 Vel, fps	Sec 8 d/s Vel, fps	Sec 10 Vel, fps	Sec 2.8 Vel, fps	Sec 8 d/s Vel, fps	Sec 10 Vel, fps
1	3.72	4.04	4.24	4.93	5.40	5.85
2	5.30	3.20	4.41	5.33	5.47	5.97
3	5.33	3.91	4.41	5.32	5.47	5.97
4	3.53	3.31	4.26	4.78	5.26	5.88

Project Impacts to Novato Creek Flow Rate - Impacts due to Pacheco Pond and the design breach on channel flow rate were assessed in a similar manner as the stage impacts and velocity impacts, and are summarized below.

- **Impact of levee breach –** As shown in Figures 8 and 9, the levee breach has no appreciable effect on flows at Sections 8 ds and 10. Downstream of the design levee breach (Section 2.8), the computed flow rate for both ebb and flood tide conditions on Novato Creek increases due to the draining and filling of the tidal prism in the proposed tidal wetland.

- **Impact of removing Pacheco Pond –** Removal of Pacheco Pond flows reduces the peak flow on Novato Creek at Section 2.8 and 8 ds, as summarized in Table 5. These reductions in flow and volume are shown in the flow time series histories on Figures 8 and 9.

Table 5. Summary of Peak Novato Creek Flow

	Flow Condition A			Flow Condition B		
Scenario	Sec 2.8 Flow, cfs	Sec 8 d/s Flow, cfs	Sec 10 Flow, cfs	Sec 2.8 Flow, cfs	Sec 8 d/s Flow, cfs	Sec 10 Flow, cfs
1	3230	2180	1740	4710	3870	3740
2	5180	1760	1740	5910	3490	3740
3	5180	2140	1740	5180	3810	3740
4	3270	1770	1740	4460	3480	3740

Project Impacts to Pacheco Pond Stage – The stage of Pacheco Pond was computed for all geometric and hydrologic scenarios. The proposed rerouting and expansion of Pacheco Pond substantially reduces the peak water surface elevation within Pacheco Pond (Table 6). Reducing stage in Pacheco Pond would improve the drainage of Ignacio Business Park and other low-lying areas adjacent to lower Arroyo San Jose, such as the nearby trailer park. The magnitude and extent of this improvement, however, was not quantified in this analysis.

Table 6. Peak Water Surface Elevations in Pacheco Pond (ft, NGVD 29)

Case	Scenario A	Scenario B
Existing	6.4	7.6
Alternative 1 & 3	4.5	7.2
Revised Alternative 2	4.6	6.3

The volume of water overtopping the Bel Marin Keys V levee from Novato Creek during the Scenario 1 (existing condition) Flow Condition A, which loosely represents the current 100-year Novato Creek flood, is 5 ac-ft. The duration of overtopping is less than 2 hours and has a peak discharge over the levee top of less than 60 cfs. The flow overtopping into the BMKV site during Scenario 1 Flow Condition A is less than 0.2 percent of the inflow hydrograph at the upstream Novato Creek boundary (Section 10).

Conclusion

The proposed levee breach and potential diversion of Pacheco Pond inflows reduces peak water surface stages in Novato Creek. The proposed tidal wetland connection to Novato Creek slightly increases channel velocity downstream of the proposed levee breach. Rerouting of Pacheco Pond reduces the duration of high velocities above the levee breach during the infrequent flood flows (approximately 1 in 10 or 100 years) modeled for this study. As described in the memorandum titled *Novato Creek Geomorphic and Hydraulic Modeling Technical* (**nhc** 2002b) hydraulic properties associated with daily tidal cycles are the dominant influence on tidal channel morphology. The proposed project will have no measurable impact on tidal hydraulics upstream of the design breach and will increase the tidal prism downstream of the design breach. This increase in tidal prism results in an increase in the channel dimensions downstream of the breach. The results indicate a reduction in stage on Novato Creek for all project conditions. The project alternatives all resulted in a reduction in flood stage on Novato Creek. The volume of overtopping into the BMKV levee from Novato Creek under existing conditions is negligible, and has no measurable impact on flood stage reduction on Novato Creek.

References:

Charles D. Anderson, Katherine M. Oven, Christy Chung, 2000. "Surf's Up – or Tide Cycles During Storm Events." Spring 2000 Floodplain Managers Association Conference, San Diego, CA.

Federal Emergency Management Agency (FEMA). 1989. Flood Insurance Study, City of Novato, California

Federal Emergency Management Agency (FEMA). 2002. Map Modernization Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses. www.fema.gov/mit/tsd/dl_cgs.htm

Madrone Associates Environmental Consultants. 1975. Final Environmental Impact Report Ignacio Industrial Park, Unit 3.

Northwest Hydraulic Consultants (**nhc**). 2002a. Hydrologic and Hydraulic Modeling Assessment of Existing and Project Alternatives at Bel Marin Keys V, April 18, 2002.

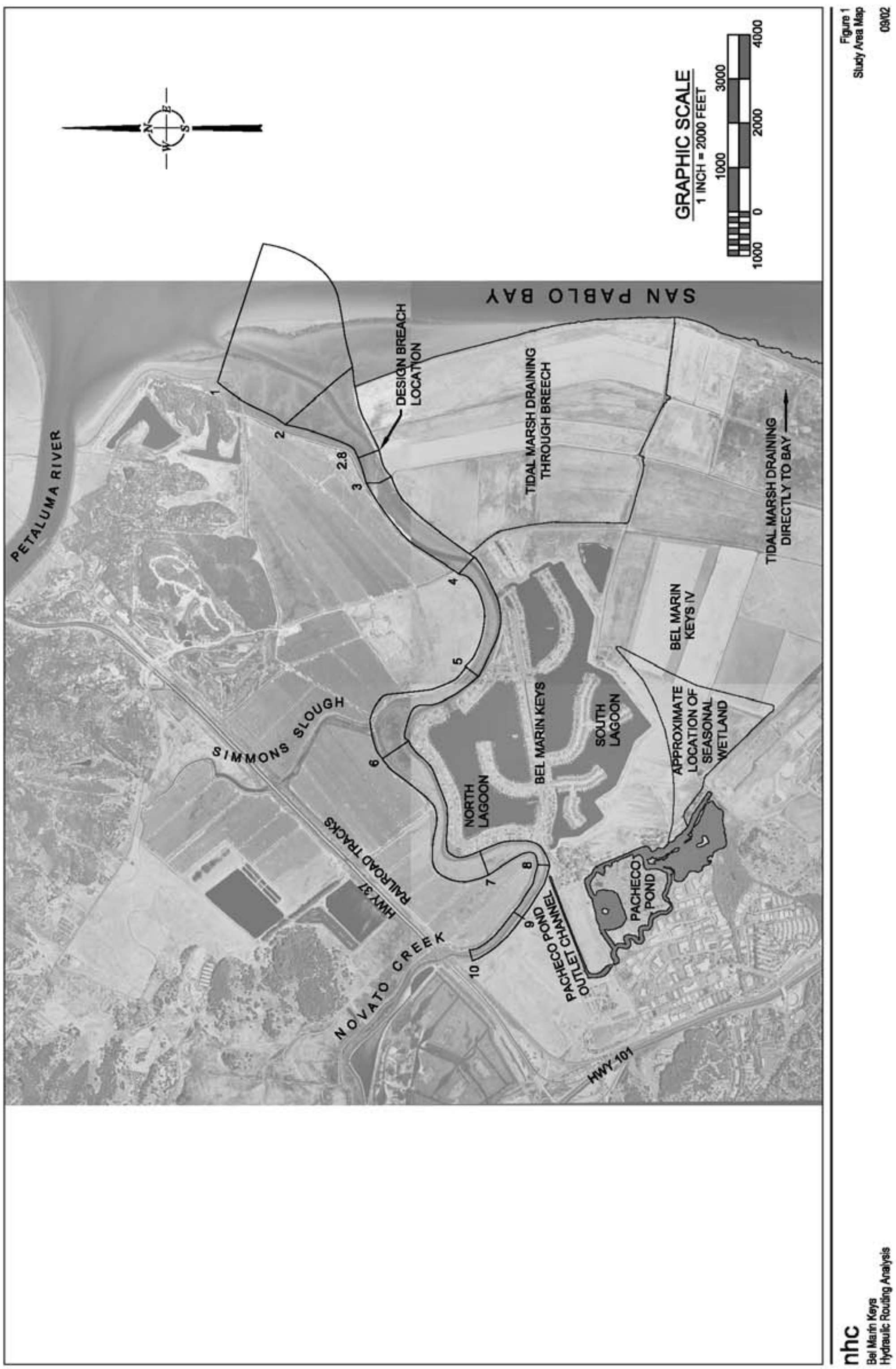
Northwest Hydraulic Consultants (**nhc**). 2002b. Novato Creek Geomorphic and Hydraulic Modeling, September 18, 2002.

Philip Williams & Associates Ltd. (PWA), 1998 (October), "Appendix E: Hamilton Base Realignment & Closure, Wetland Conversion Alternative: Airfield Panhandle Flood Assessment", Prepared for IT Corp.

U.S. Army Corps of Engineers, San Francisco District, 1987 (Corps), "Hydrologic Engineering Report, Novato Creek and Adjacent Streams", City of Novato, Marin County, California.

San Francisco District, Corps of Engineers, 1984. "San Francisco Bay, Tidal Stage vs. Frequency Study," San Francisco, CA.

Towill, Inc. 1996. "Hydrographic Survey of Novato Creek performed on July 31 and August 1 for the Bel Marin Keys Community Services District." San Francisco, CA.


PETALUMA RIVER
SAN PABLO BAY
DESIGN BREACH LOCATION
TIDAL MARSH DRAINING THROUGH BREECH
TIDAL MARSH DRAINING DIRECTLY TO BAY
BEL MARIN KEYS IV
APPROXIMATE LOCATION OF SEASONAL WETLAND
BEL MARIN KEYS
NORTH LAGOON
SOUTH LAGOON
PACHECO POND
PACHECO POND OUTLET CHANNEL
SIMMONS SLOUGH
RAILROAD TRACKS
HWY 37
NOVATO CREEK
HWY 101
1
2
2.8
3
4
5
6
7
8
9
10
GRAPHIC SCALE
1 INCH = 2000 FEET
1000
0
1000
2000
3000
4000
N
E
S
W
nhc
Bel Marin Keys
Hydraulic Routing Analysis
Figure 1
Study Area Map
09/02

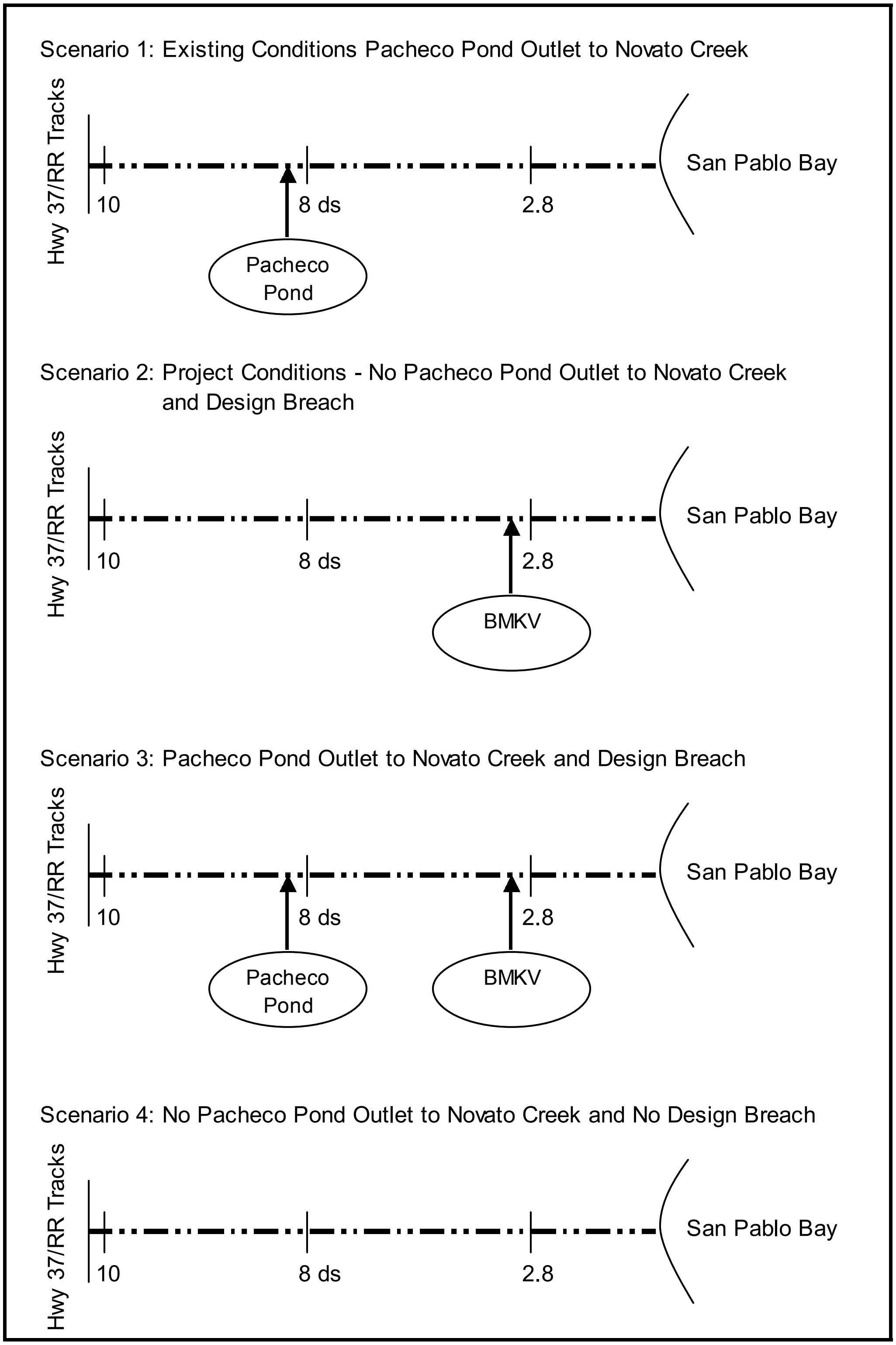


Figure 2. Geometric Scenario Schematic Diagrams

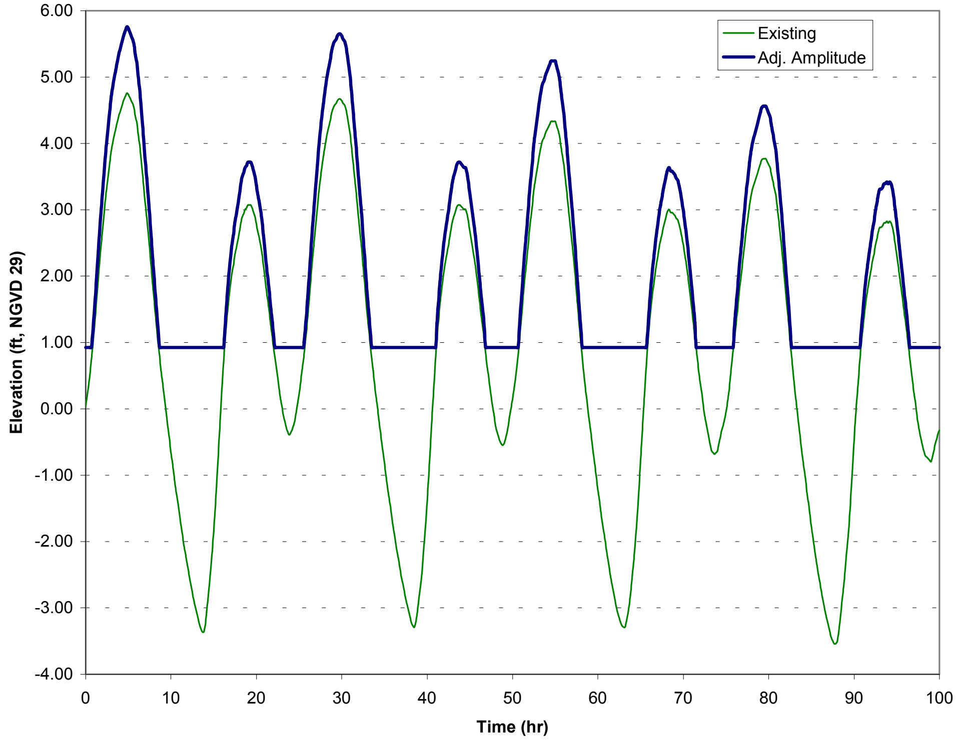


Figure 3. Tidal Boundary Condition

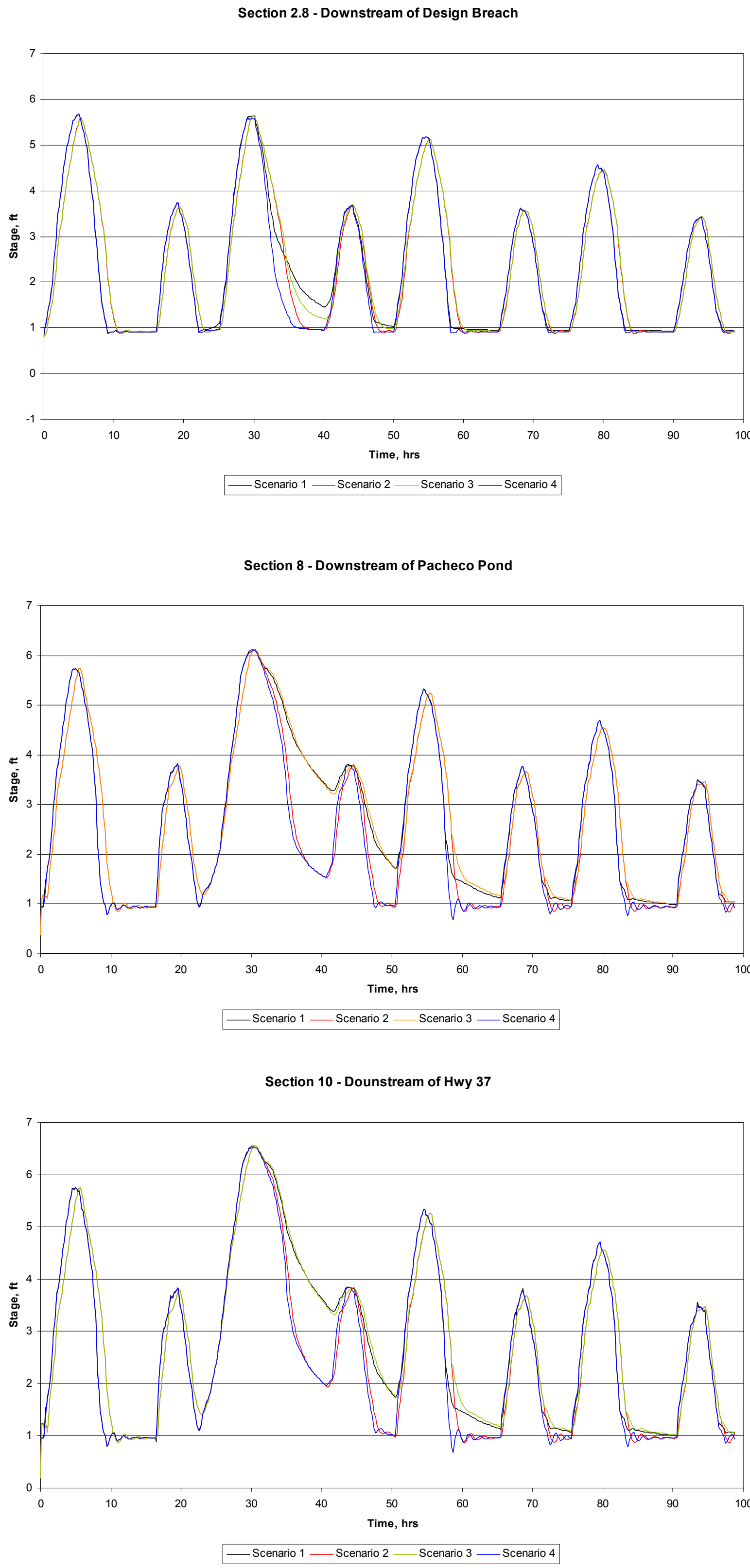
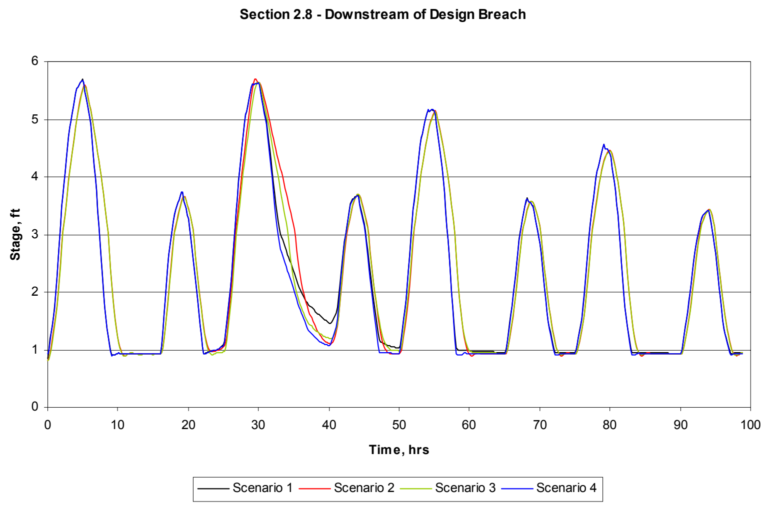
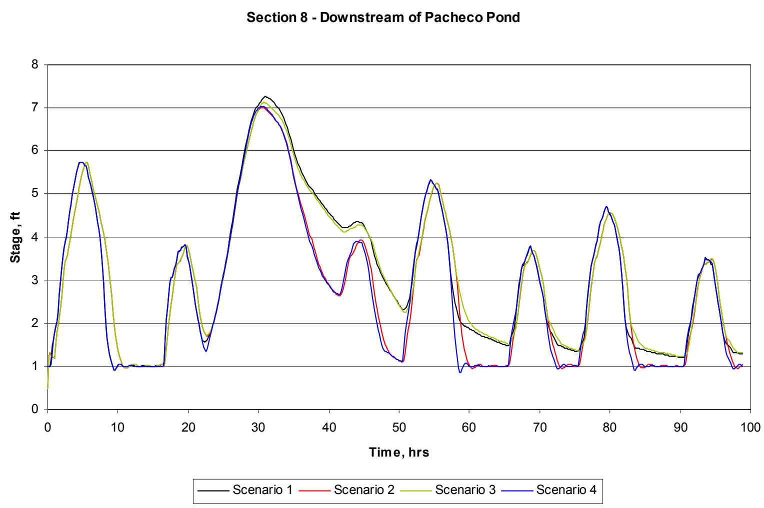


Figure 4. Stage Time Series Histories for Flow Condition A





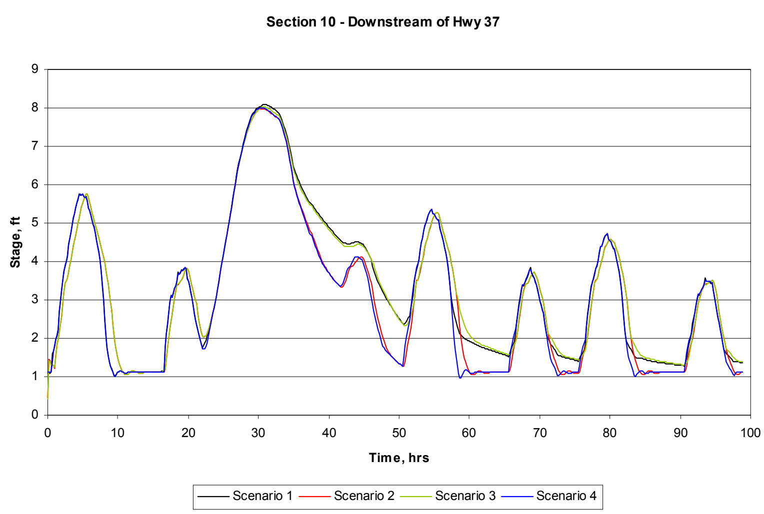


Figure 5. Stage Time Series Histories for Flow Condition B

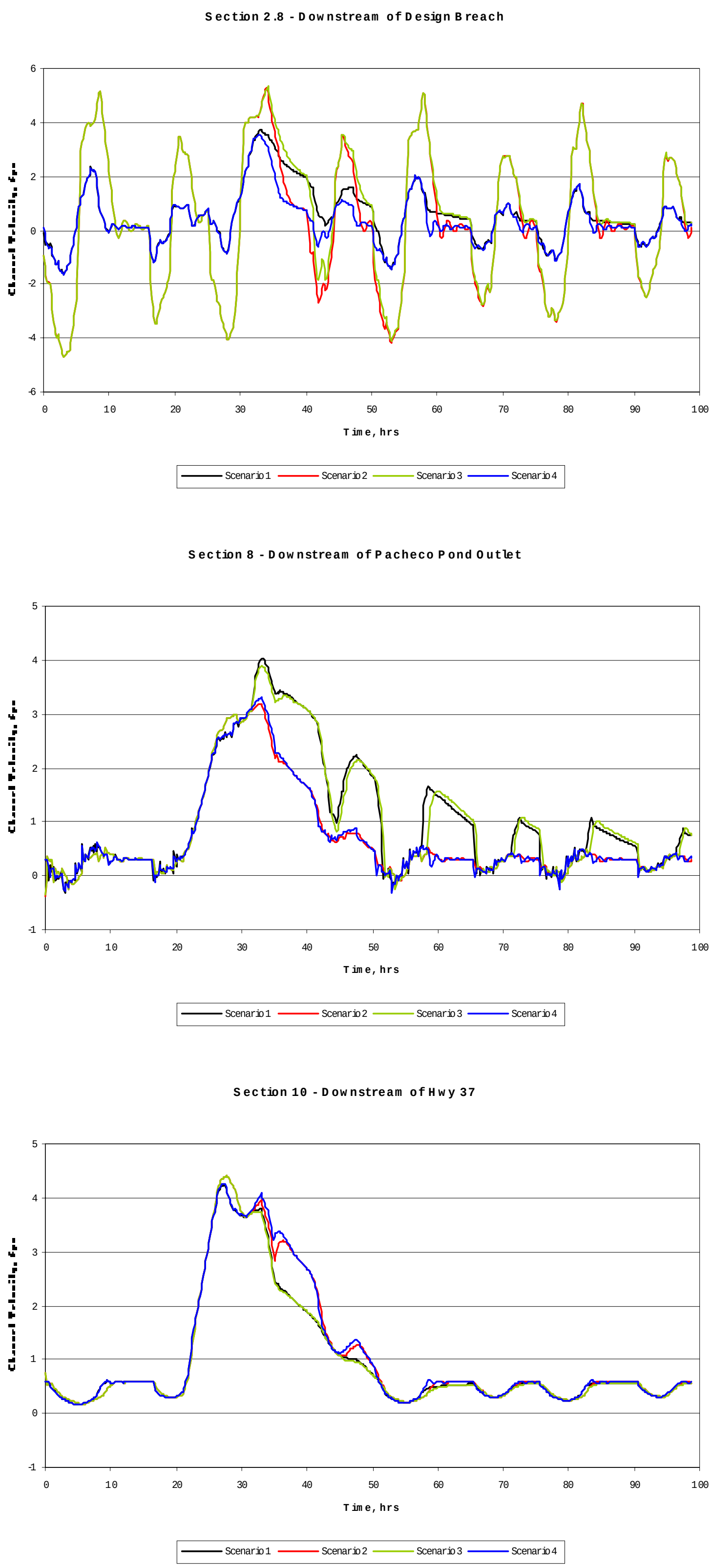


Figure 6. Velocity Time Series Histories for Flow Condition A

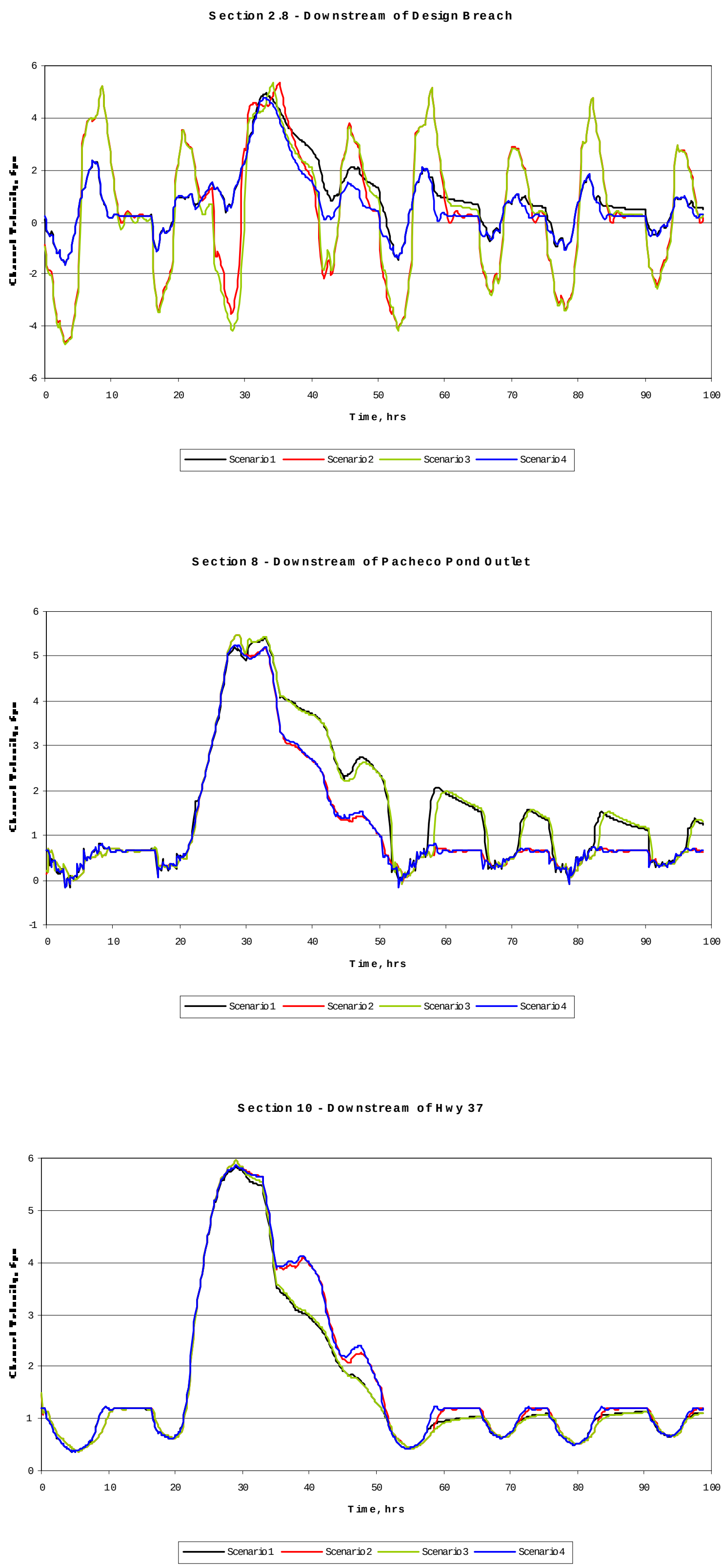


Figure 7. Velocity Time Series Histories for Flow Condition B

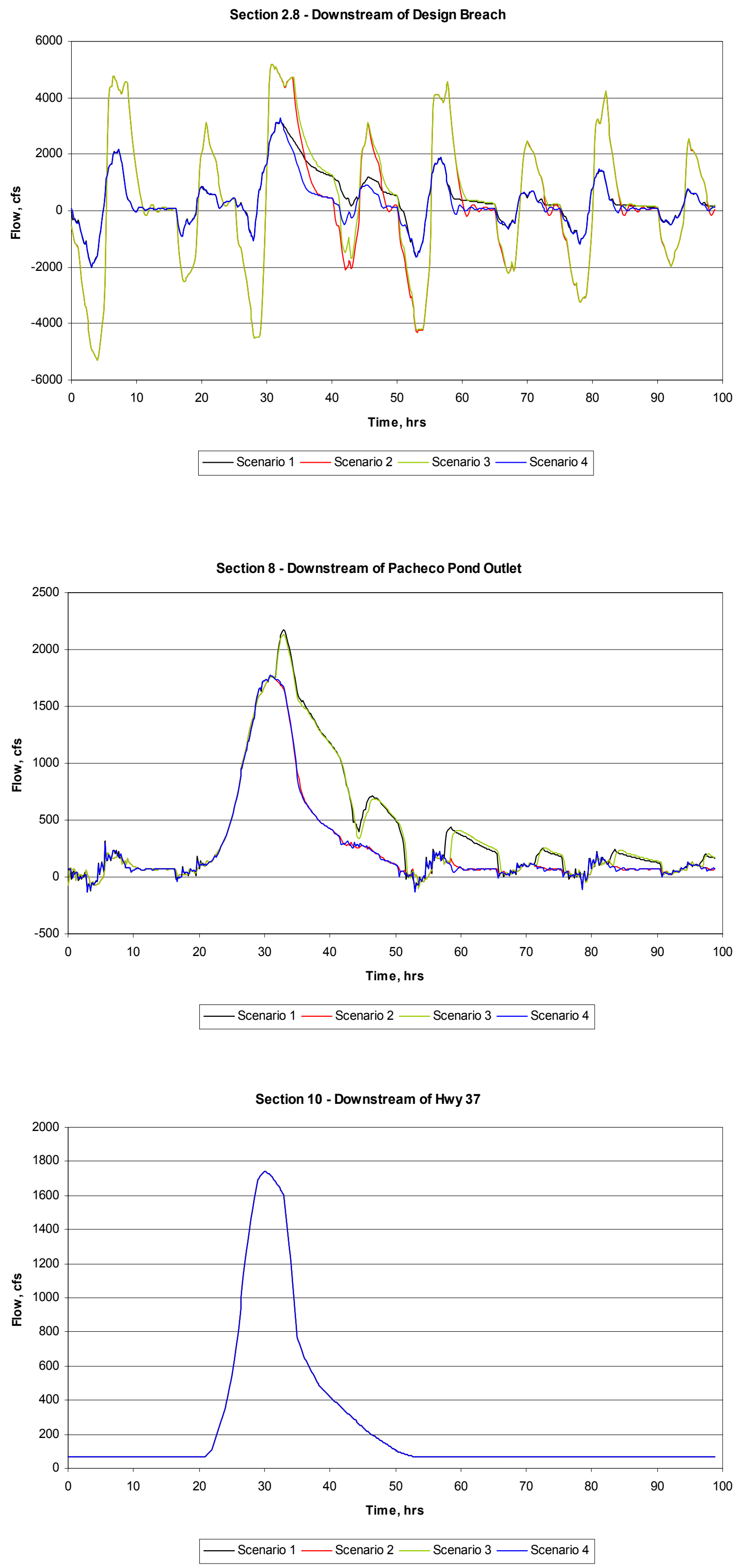
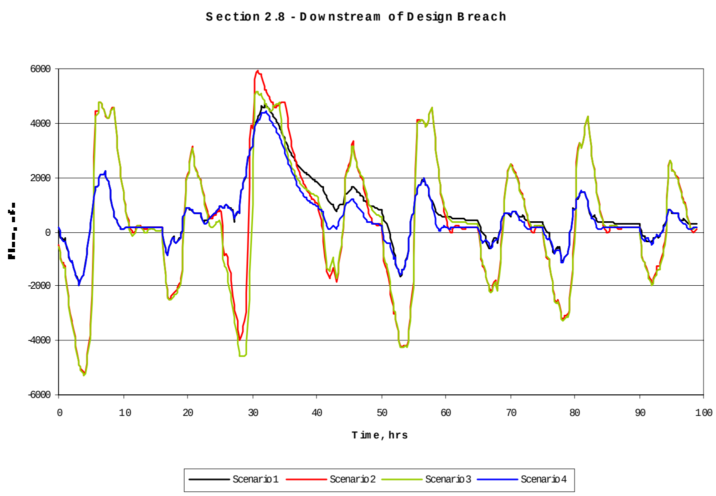
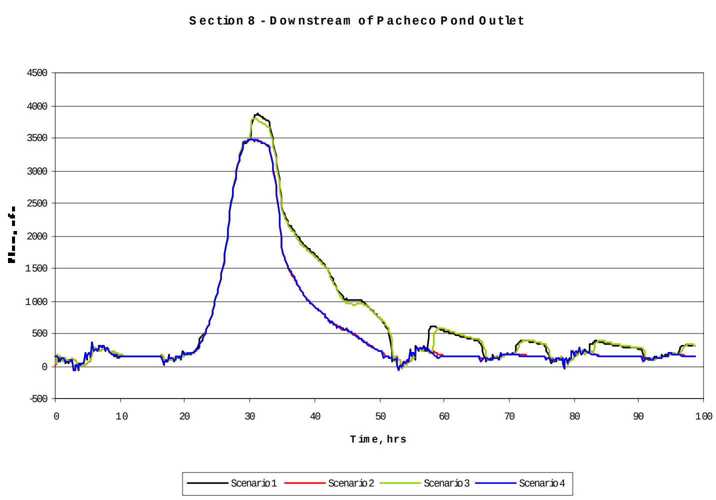


Figure 8. Hydrographs for Flow Condition A





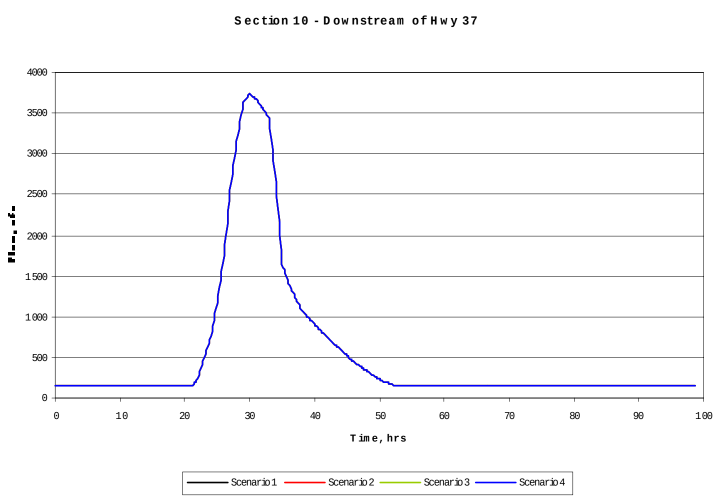


Figure 9. Hydrographs for Flow Condition B

Memorandum

northwest hydraulic consultants
3950 industrial boulevard, suite 100c
west sacramento, ca 95691
(916) 371-7400
(916) 371-7475 (fax)

Date:	October 14, 2002	Project: 50283
To:	Rich Walter	
Company/Agency:	Jones & Stokes	
From:	Brad Hall	
Subject:	Bel Marin Keys EIR Background Study	

Novato Creek Geomorphic and Hydraulic Modeling

The Bel Marin Keys (BMK) conceptual design plans call for a breach in the Novato Creek containment levee to provide tidal exchange to a proposed marsh basin near the mouth of the creek. The addition of 400 to 600 acres of tidal marsh to the existing system would enlarge the tidal prism of the creek and increase the tidal discharge in the channel reach between the breach and San Pablo Bay. To better understand the effects of the proposed breach, an unsteady hydraulic model of Novato Creek was developed and tested. Also, an empirical investigation of the surrounding tidal mudflat channel and shoals at the mouth of the creek was implemented. This memorandum discusses the background, methodology, and general results of these investigations.

Novato Creek Modeling Approach

UNET, a one-dimensional hydraulic model developed by the U.S. Army Corps of Engineers, was used to determine channel velocities in Novato Creek from tidal exchange. The marsh basin was specified as a storage area connected to the creek by the levee breach. The time series tide data used for the analysis were measured by ADEC and obtained at the mouth of the Petaluma River. Measurements were taken at 10-minute intervals over a full month period during the summer of 2000. The data was adjusted slightly so that mean sea level of the data correlated with the observed mean sea level of San Pablo Bay at the mouth of the Petaluma River (0.62 feet NGVD). No adjustments were made to the data to account for frequency or lag effects.

Cross sections for Novato Creek were developed from an algorithm that related slough channel top width to channel side slope and base width. This relationship was created by Northwest Hydraulic Consultants using data from various sloughs and channels located in the San Francisco Bay area, including Novato Creek. The equations relating the hydraulic parameters were of the form:

$$m = m_1 T^{m_2} \tag{1}$$

$$b = b_1 T \tag{2}$$

where *m* and *b* are the typical channel side slope and base width, respectively, associated with a top width *T*. The constants m_1, m_2, and b_1 were determined to be 0.13, 0.67, and 0.5, respectively, such that the hydraulic characteristics of the predicted and observed cross sections were as similar as possible. Equations 1 and 2 were then used to estimate the existing and likely future geometries of Novato Creek during the hydraulic and geomorphic modeling processes. Top widths on Novato Creek and other tidal sloughs adjacent to San Pablo Bay were measured from infrared aerial photographs taken by Air Flight Services in September of 2000.

The modeling procedure for estimating the widening of Novato Creek was an iterative process. Using the 30-day tide data and UNET, channel velocities and water surface profiles were calculated in the creek. This information was used to estimate shear stresses that developed along the channel boundary at each time step. Each value of computed shear stress, in turn, was used to estimate the incremental erosion that would take place along the channel according to the empirical equation:

$$E = M \frac{\tau - \tau_{cr}}{\tau_{cr}} \tag{3}$$

where *E* is the erosion rate, τ is the average boundary shear stress at a cross section, τ_{cr} is the critical shear stress for erosion, and *M* is an erosion coefficient.

A wide range of values is presented in the literature for the erosion coefficient. The values ranged from a low of 0.003 g/m^{2}sec found by Mehta et al. (1994) to a high of 5.0 g/m^{2}sec calculated by Ariathruai and Arulanandan (1978). In an effort to establish a suitable value for *M*, erosion data were obtained from slough channels between the years of 1994 to 1998 at Sonoma Baylands (Phillip Williams and Associates, 1999) and 1997 to 1999 at the Oro Loma Marsh (Lenington, 2001). From analysis of the data, an erosion constant of *M* = 0.015 g/m^{2}sec was established, which produced erosion rates of about 0.5 to 3 feet per year in channels with peak velocities between 3.5 and 6 feet per second.

Critical shear stress is a function of many variables including the physical and chemical properties of the eroded soil, and density and type of vegetative cover.

A midrange value of τ_{cr}=0.75 N/m^2 was adopted as a reasonable compromise. This value also produced modeling results that agreed well with the stable channel threshold velocity range of 2.5 to 3 feet per second.

Channel roughness in UNET is modeled using the Manning Equation and an associated Manning's 'n' coefficient. The coefficient accounts for hydraulic energy losses due to friction, which are responsible for the phenomenon of tidal muting. An appropriate value for Manning's n was developed using both published values and an empirical calibration of the Skaggs Island UNET model. Weisman et al. (1989) calculated coefficient values that ranged between 0.0125 and 0.0202. Chow (1959) listed values of 0.020 to 0.025 for channels made of fine silts and clays. Barnes (1967) suggested a value of n=0.026 for the Indian Fork River, which has a clay channel and a flat slope. Leopold et al. (1993) found somewhat higher roughness values for local tidal channels that ranged between 0.028 and 0.063.

For this study, Manning's n was determined by trial and error using tide data collected by ADEC (2000) and Warner and Schoellhamer (1999). Both data sets include tide data collected at the lower end of Sonoma Creek and at Hudeman Slough at the northern end of Skaggs Island. The data indicate that full tidal exchange occurs at both stations, with a lag time of about 30 to 40 minutes. With this in mind, a UNET model of the existing slough network around Skaggs Island was developed specifically to calibrate Manning's n for the system. By trial and error, it was observed that tidal muting disappeared in the model when using a roughness coefficient of n=0.02. This value was, therefore, defined as the slough channel roughness coefficient. The marsh plains were assumed to be much rougher than the channels due to dense vegetation and variable topography. A value of n=0.04 was assigned to these areas according to Barnes (1967), Chow (1959), and engineering judgment. UNET model results were relatively insensitive to the value of the marsh plain roughness.

Mudflat Modeling Approach

To estimate the potential effects of the proposed restoration on the mudflats, or shoals, at the mouth of Novato, a study of existing mudflat channels was performed. This study consisted of using bathymetric data and newly established transects in established mudflat channels around the bay to develop a relationship between mudflat channel top width and upstream tidal prism volume.

Typical mud flat cross sections were selected where the average mud flat elevation was approximately -0.5 m, NGVD 29. Tidal prism volumes in the upstream basins were estimated using the planform area of the observed channels multiplied by the vertical range in tides (MHHW to MLLW). Figure 1 presents the relationship observed between mud flat channel width and upstream

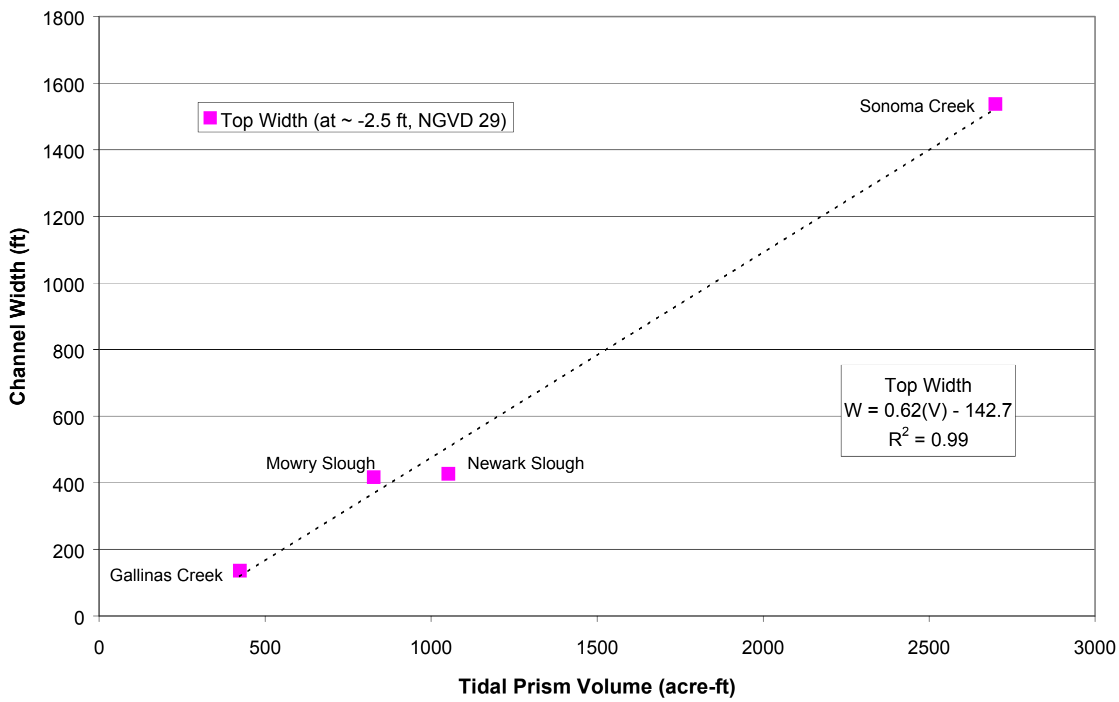


Figure 1. Mudflat channel width as a function of upstream tidal prism volume.

tidal prism volume. A best-fit line was added to the data points to correlate mud flat channel size to basin volume. Because the relationship presented in Figure 1 is linear, an increase in basin volume should result in a proportional increase in mudflat channel top width. The estimated volume of the proposed marsh basin is about 800 acre-feet at MHHW, assuming equilibrium marsh plain elevations. According to Figure 1, this corresponds to a mudflat channel width increase of between 250 to 350 feet. The total length of the mudflat channel is approximately 2000 feet.

Modeling Results and Discussion

The hydraulic and geomorphic modeling of the lower Novato Creek suggested that the 140-foot wide channel downstream of the breach would increase by 10 to 40 feet in width and about a half to one foot in depth due to the addition of the proposed marsh basin connection. This corresponds to about 2 to 5 acres of eroded marsh flood plain. The shoal analysis predicted a loss of approximately 10 to 15 acres of existing mudflat due to the basin connection, which would likely occur along the sides of the mudflat channel. The invert elevation of the mudflat channel may also decrease slightly due to the addition of the marsh basin. The marsh restoration project is expected to develop 400 to 600 acres of new tidal marsh connected to Novato Creek and over 50 acres of new fringe mud flat. Therefore, these impacts are considered to be less than significant.

The erosion of the Novato Creek channel downstream of the levee breach would occur slowly over time due to increases in flow and channel velocity. The hydraulic model predicted a peak tidal flow increase from an existing 1500 cfs to between 3000 and 5000 cfs with the breach in place. Velocity increases will be most apparent immediately downstream of the breach where the channel width is most constricted. Existing peak tidal velocities of 2 feet per second will increase to 4 to 6 feet per second in some sections for existing Novato Creek channel configurations. This increased velocity is contained to the subtidal channel section, and leads to the predicted widening of the lowermost tidally influenced reach of Novato Creek. Because the perimeter levees are set back from the main channel near the mouth of the creek, and because the flow is forced over an elevated and highly roughened flood plain during high tides, the velocity increases near the levee due to the breach would be negligible or zero. Therefore, the increase in channel velocity would not threaten the structural integrity of the confining levees.

References

ADEC 2000. Text file and EXCEL spreadsheet with bathymetry and tide data from San Pablo Bay. Received by Northwest Hydraulic Consultants, Inc. in August.

Ariathurai, Ranjan and Kandiah Arulandandan. 1978. “Erosion Rates of Cohesive Soils.” Journal of the Hydraulics Division. 104.2:279-83.

Barnes, H.H., Jr. 1967. Roughness Characteristics of Natural Channels. U.S. Geological Survey WSP 1848.

Chow, V. T. 1959. Open Channel Hydraulics. New York: McGraw-Hill.

Lenington, Kirk. 2001. Oro Loma Marsh Monitoring Report 1999 to 2000. A report submitted to Hayward Regional Shoreline. Santa Cruz, CA: Lenington Ecological Services.

Leopold, L.M., Collins, J.M., Collins, L.M. 1993. "Hydrology of some tidal channels in estuarine marshland near San Francisco." *Catena*. v.20. p. 469-493.

Mehta, Ashish J., et al. 1994. Analyses of Some Sedimentary Properties and Erodibility Characteristics of Bottom Sediments from the Rodman Reservoir, Florida. Report submitted to Environmental Consulting and Technology, Inc. Gainesville, FL: Coastal and Oceanographic Engineering Department, University of Florida.

Phillip Williams and Associates. 1999. 1997-1998 Final Annual Monitoring Report. Report submitted to San Francisco District Corps of Engineers. Corte Madera, CA.

Warner, J.C., Schoellhamer, D.H. 1999. "Summary and analysis hydrodynamic and water-quality data for the Napa/Sonoma Marsh Complex, Final Report." USGS/UCD. 36 pp.

Weisman, Richard N., Gerard P. Lennon, Fred E. Schuepfer. 1989. “Resistance Coefficient in a Tidal Channel.” Estuarine and Coastal Modeling. Ed. Malcolm L. Spaulding. New York: American Society of Civil Engineers.